Figure 42 shows still another example of a hardware source. A close inspection of the wood behind the insulator shows extensive cracking and dry rot. This loosened the support bolts and associated hardware, and allowed sparking and micro-sparking sources to form on the insulator support components. Occasional puffs of smoke were seen emanating from the cracks due to the conduction of carbonized wood.

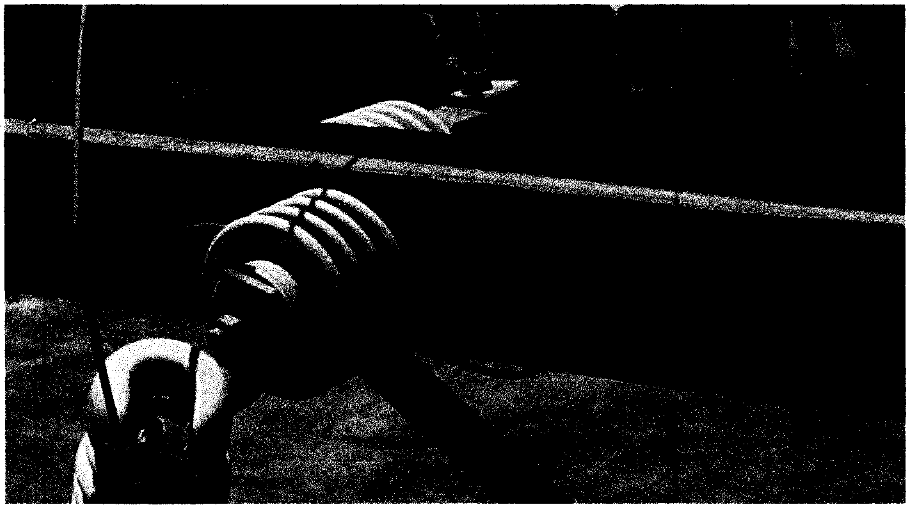

Figure 42 Hardware Source, Example 3

Figure 43 shows still another example of a hardware source. In this case the line construction crew carelessly left a loose bolt in a hole on the end of a metal crossarm. Movement of the bolt from wind or pole movement caused an intermittent and erratic micro-sparking source to exist.

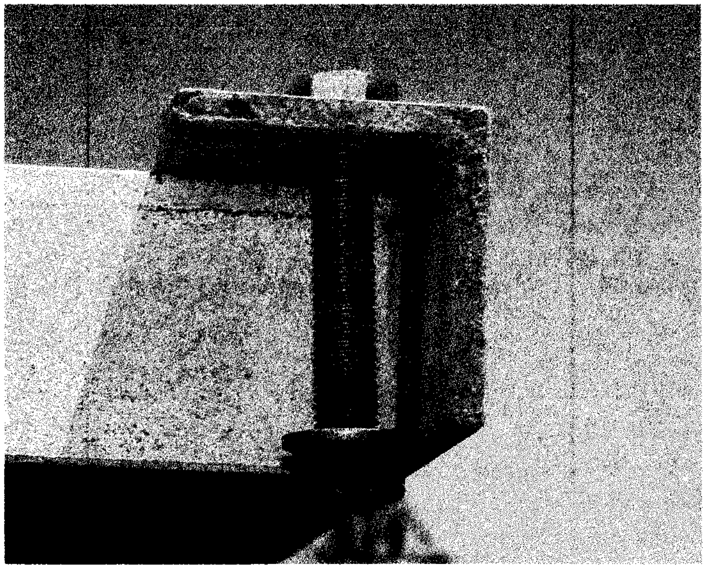

Figure 43 Hardware Source, Example 4

Debris can sometimes be found hanging on the conductors of a distribution line or from other nearby conductors. Such metal objects form intermittent contacts with a conductor whose electrical properties change with wind and moisture. A small layer of rust can develop between such an object and the line conductor which will break down from the difference in potential between the line and the debris. Such mechanisms generate highly erratic impulses of noise with noise bursts synchronous with the line frequency.

Figure 44 shows an example of debris found hanging on the conductor of a distribution line while trying to locate a highly intermittent and erratic source of noise at a receiving site. In this case, a child's swing seat was tossed onto the line by mischievous teen-age youngsters who were playing in the street.

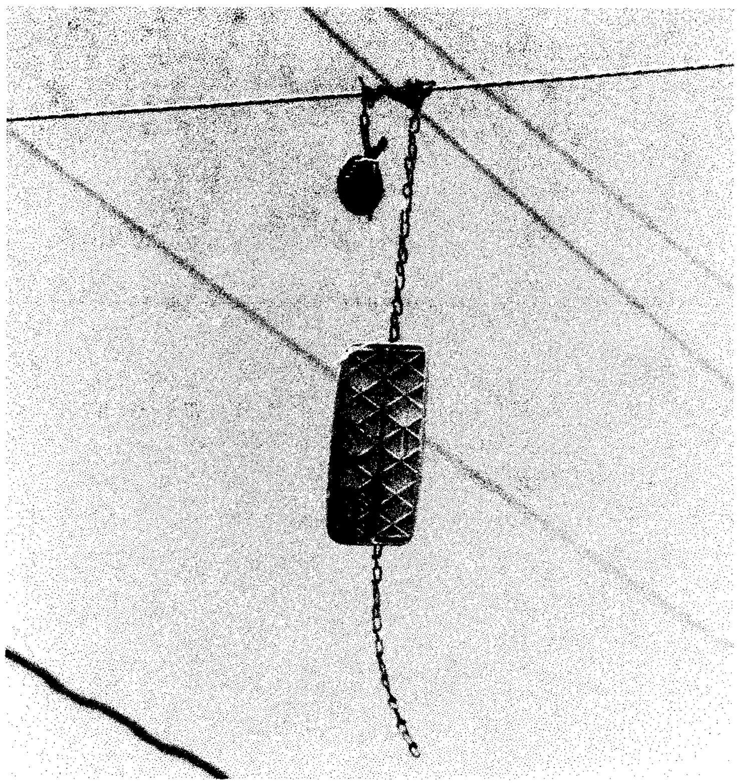

Figure 44 Debris on a Distribution Line Conductor

Other kinds of debris can be very difficult to spot since the object can be a small piece of wire or other very small metal object. For example a small piece of wire or metal object can be blown onto an overhead conductor by wind, a piece of tie-wire can work its way along a conductor from line movement, or small pieces of debris can be flung up onto a line by a power mower. While most noise sources are associated with line-support hardware on a pole, debris can be found anywhere on or between line-support hardware, and is often found in mid-span, at the lowest point on a line conductor. In many cases the debris is very difficult to visually locate.

3.1.6 Spool Insulators

Spool insulators are occasionally found on distribution lines although they were designed for (are more often found on) lower-voltage secondary lines. Figure 45 shows an example of a spool insulator that was removed during the upgrading of a distribution line. The line conductor is supported by passing it through the spool at the right end of the insulator assembly. The left clevis is attached to pole hardware. Often an insulated conductor is used to increase the insulation protection of the line.

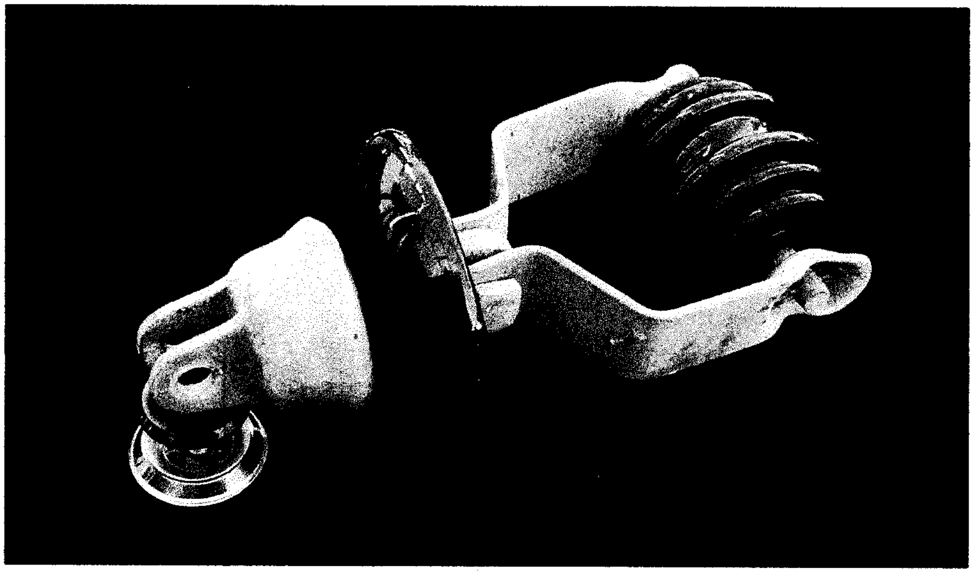

Figure 45 Spool Insulator

The spool insulator is often a source of radio noise for two reasons. First, the spacing between of the line conductor from the metal support parts of the insulator is minimal, and under some conditions this can result in sparking. Next, the capacitance between the line conductor and the metal support parts of the spool is sufficient to pass a charge through the spool and onto the insulated metal spool-support hardware. The capacitance across the single section of the bell on the spool is similar to that of a bell insulator. These two factors can result in microsparking at the metal-to-metal junctions of the insulator similar to that described earlier for the bell insulator. Furthermore if insulated conductors are used with a spool, the insulation can break down, resulting in sparking and microsparking sources similar to that generated by an insulated tie wire.

Lastly, insulated tie wires are sometimes used to attach bare or insulated line conductors onto the spool, and this can result in the tie-wire to conductor breakdown along with the resulting combinations of sparking and microsparking source mechanisms described earlier for tie wires.

Figure 46 shows a spool insulator used at the end of a short span of overhead conductor. The tie wire fastening the conductor to the spool is insulated. In addition, the conductor is wrapped with plastic insulation. This combination is especially prone to breakdown and the generation of sparking sources.

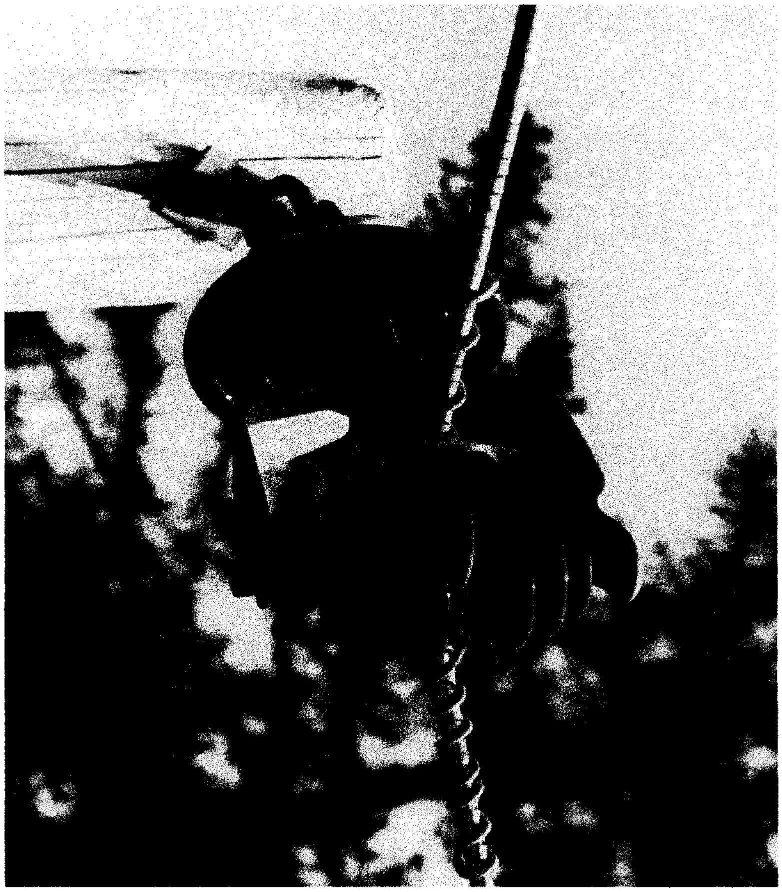

Figure 46 Spool with Insulated Tie Wire and Insulated Conductor

Several cases of the conductor slipping off a spool due to a loose tie wire have been noted. In such cases the conductor often comes in direct contact with the spool support metal, causing a metal-to-metal contact with the resulting erratic radio noise.

Because of the propensity of spool insulators to support one or more noise sources, their use on distribution lines is strongly discouraged. This is especially true of distribution lines located within line of sight of a receiving site.

3.1.7 Underground Distribution Lines

Underground electrical distribution is generally considered to be noise quiet, but there are notable exceptions. Some of these exceptions are described in this section.

Customer sources of noise can be conducted over a section of an underground distribution line and onto overhead lines, and radiation of the noise from the overhead portion of the distribution system can be encountered at a receiving site. The source will appear to be at the transition from the underground to the overhead line. Most cases of such noise will have a distinctive temporal structure that will provide considerable information about the type of source. Facilities obtaining their electric power from the underground portion of the distribution system must then be examined to locate and identify the source device. Often there will be sufficient radiation from a facility containing a source that it can be located by measurement from nearby roads and parking lots with the instrumentation used to locate poles with sources. In most cases, the facility containing the source will be located a short distance from the underground-to-overhead transition.

The insulation used on underground lines experiences high levels of dielectric stress, and failures in the insulation can occur. A sparking type of source from initial stages in the breakdown process can result in small local areas of noise emanating directly from the underground line. Fortunately, such noise rapidly attenuates along the underground line and only radiates harmful levels of noise from an overhead line if the source is close to an underground-to-overhead transition. The temporal structure of such a source usually starts with a single small spark and progresses to multiple overlapping sparks. Such sources should be reported to the electric utility operating the underground line since insulation breakdown eventually progresses to total failure.

The most prevalent sources of noise related to underground construction are the transitions from an underground cable to an overhead line, the transition of an underground line to the terminals of a surface-mounted transformer, and the transition from an underground cable to switch gear. It is sometimes difficult to distinguish such sources from those caused by a nearby cable insulation failure.

The metal enclosure housing a surface-mounted customer transformer or switch gear is normally grounded for safety considerations. In rare cases the ground connection can be broken. When this is the case, a sparking source inside the enclosure can induce surface currents on the outside of the enclosure. Radiation from the surface current can be a source of noise at a nearby receiving site.

Problems arising from underground construction peculiarities and transitions from underground to surface hardware are difficult to identify and resolve, and they will present the radio-noise investigator with great challenges in properly identifying the actual source mechanism and prescribing practical and effective mitigation actions. Only experienced utility or public works personnel should obtain access to, and work on, underground cables and the transition to surface hardware because of the specialized construction and the safety considerations involved.

3.2 Power-Conversion Sources

3.2.1 Background Information

Devices to convert electrical power from one form to another form have been used since the early days of the distribution of electricity, but the relatively recent development of solid-state switching devices capable of handling large currents and withstanding large potentials has greatly expanded applications for these devices. They are presently used to change alternating current to direct current, direct current to alternating current, 50- or 60-Hz current into variable-frequency current, and many other tasks. The switching process breaks the power into a series of short pulses of current and voltage. These short pulses (with steep rise and fall times) have spectral components that extend up into the HF and VHF frequencies and sometimes even higher into the UHF band.

The first through fourth editions of this handbook did not mention radio noise from power-control devices, because they simply were not a major source of radio noise affecting the operation of receiving sites. By the time the fifth edition was published, it was apparent that such devices were becoming a significant source of radio noise, and their numbers would increase over the next few years. Unfortunately, not enough information about the radio-interference aspects of power-control devices had been collected to fully document the extent of their radio-noise problem as the 5th edition was being prepared.

Every desktop and laptop computer uses a switching-power supply to convert the available electric supply into the various voltage levels required to operate the computer, but this is only one of a vast number of applications for solid-state switching devices. Fortunately, most of these devices are designed such that the transients produced by them are largely contained within the device. Unfortunately, some are not so designed and induce undesired electrical impulses into the power conductors of the building housing them and onto overhead power lines. Generally, it is impulsive current on the overhead power lines that is the radiation mechanism.

In the United States, the Federal Communications Commission sets limits on the amount of radio noise which switching devices and other electronic equipment can inject into the power conductors of a residence or an industrial facility. Part 15 of the FCC Rules[3] provides for two classes of protection from radio noise generated by such devices. Devices in the Class A category have limits intended to satisfy the needs of industrial facilities where significant amounts of radio noise can be tolerated. Devices in the Class B category have a stricter limit to meet the needs of residential areas where the density of radio and television receivers is high. All electronic devices marketed in the United States must be tested for compliance with the noise limits contained in the FCC Rules, and each item must have a label indicating it meets the requirements of its category.

Figure 47 shows an example of such a label for a Class A product intended for use by industry. The text on this notice clearly indicates the device might, and probably does, generate unacceptable amounts of radio noise for use in a residential area. The notice does not mention the possibility of radio noise at radio-receiving sites.

[3] Code of Federal Regulations, 47CFR Part 15, Radio Frequency Devices; Subpart B, Unintentional Radiators

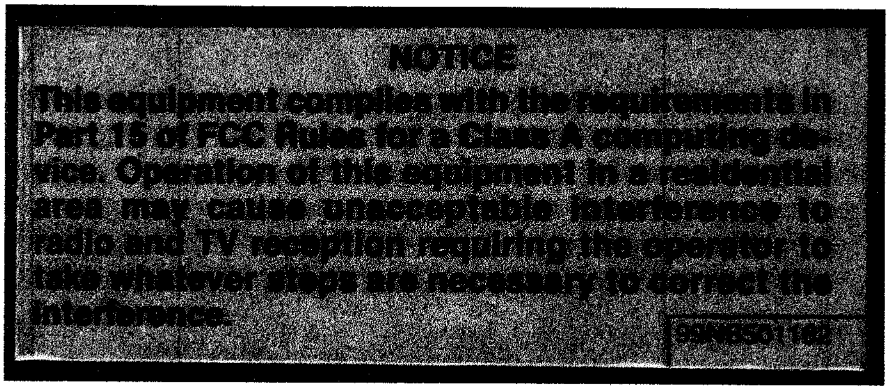

Figure 47 Radio-Interference Label from a Class A Electronic Device

Unfortunately, radio noise from a Class A device located in an industrial facility can be conducted along the facility wiring, through the meter, through a pole transformer, and onto overhead power lines providing electrical power to the facility. Overhead power lines carrying noise current efficiently radiate the noise which appears as radio interference to a nearby radio receiver. While the source of the noise is the power-conversion device, it is the conductors of an overhead power line that radiate the noise or sometimes other conductors in a building. Both the source and the conductors carrying noise current are part of the noise-source mechanism.

Radio noise originating from a number of power-conversion devices has been encountered during noise surveys at receiving sites. Among these are:

- Variable-speed controller providing power to a fractional horse power electric motor driving a pump at a hydroponics farm.
- Variable-speed controller providing power to a fractional horsepower electric motor driving a belt for sorting flowers.
- Variable-speed controller providing power to a fractional horsepower electric motor driving an exhaust fan at a ceramics furnace.
- Variable-speed controller providing power to an electric motor providing power to the air-circulating fan of a building.
- Variable-speed controller providing power to an electric motor used to drive a moving platform of a research water tank.
- Variable-current controller used to provide power to the field winding of a large electric generator located at a satellite communications facility.
- Uninterruptible power supply for a satellite receiving facility.
- Variable-frequency controller providing power to an electric motor at a water-pumping station.
- Controllers and power converters for residential solar power systems.

3.2.2 Examples of Power-Conversion Sources

Several examples of power-conversion devices are provided in this section. Each example produced harmful levels of radio noise at a receiving site. The examples show the diversity and variety of power-conversion devices and their applications.

Figure 48 shows the outside housing for the controller and motor of an air-conditioning system of a large radio-receiving facility. A radio-noise specialist is pointing at the Class A warning notice on the housing that clearly indicated this device was a likely source of radio noise. The controller injected high levels of noise current onto the outside surface of the housing, onto pipes leading to and from the housing, and onto the conduits providing power to the controller. Radio noise emanating from these conductors was intercepted by the site's antennas and fed to its receivers, resulting in severe interference to the reception of radio signals.

The variable-speed controller for the air-conditioning motor for this installation was intended for use in an industrial facility, and it was properly labeled for that type of use. The controller was improperly installed at an HF radio-receiving site where it caused severe radio interference as indicated by its warning label. This is a clear example of poor site engineering. Only devices approved for Class B residential use should be considered for installed at locations at or within line of sight of radio receiving sites. Noise measurements should be performed on selected examples, and low-noise devices selected for critical tasks.

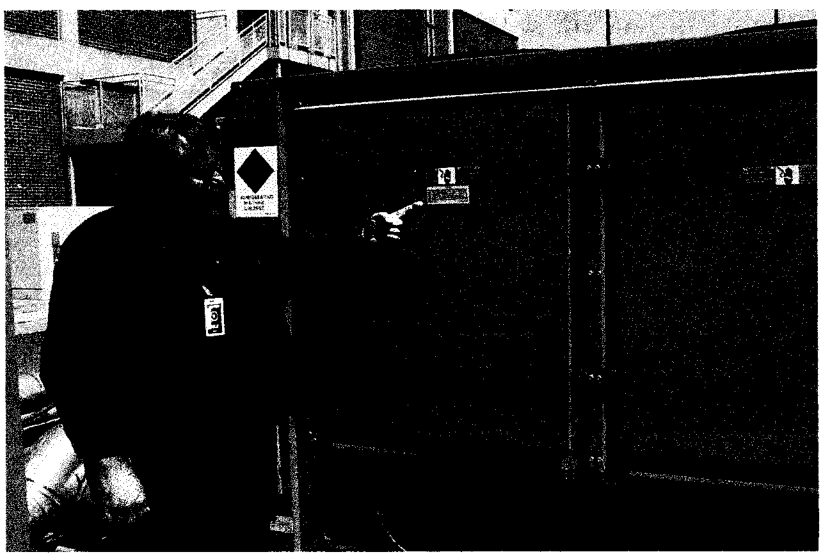

Figure 48 Housing for Variable-Speed Motor Controller and Motor

Figure 49 shows another example of a source of radio interference at a receiving site from a power-conversion device. The photograph shows the controllers for two variable-speed electric-motors used to control the flow of water from a nearby storage tank into the local-area water-distribution system. Electric power enters the controller enclosure at the bottom. The motors are located directly below and behind the controller. Variable-frequency electric-power is provided to the motors by short conductors that also exit from the bottom of the enclosure.

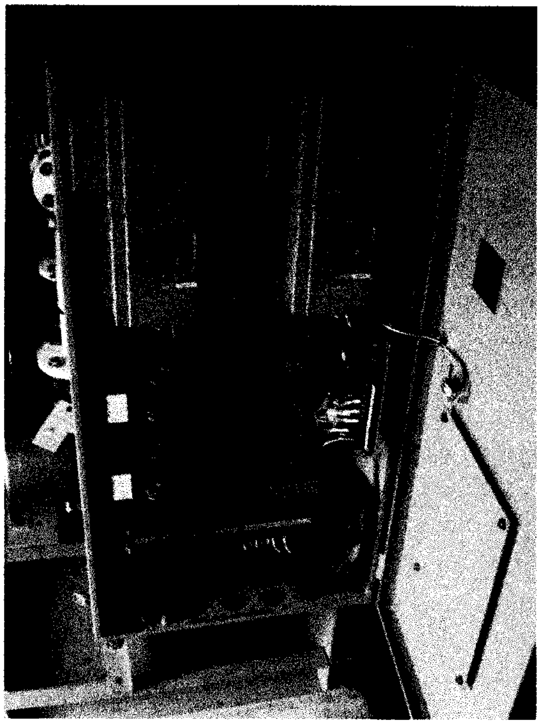

Figure 49 Variable-Frequency Controllers for Two Electric Motors

Figure 50 shows the motors and the water-control valves associated with the controller in the previous figure. The motors are standard fractional horsepower induction motors that are widely used in many kinds of low- to modest-size variable-speed applications.

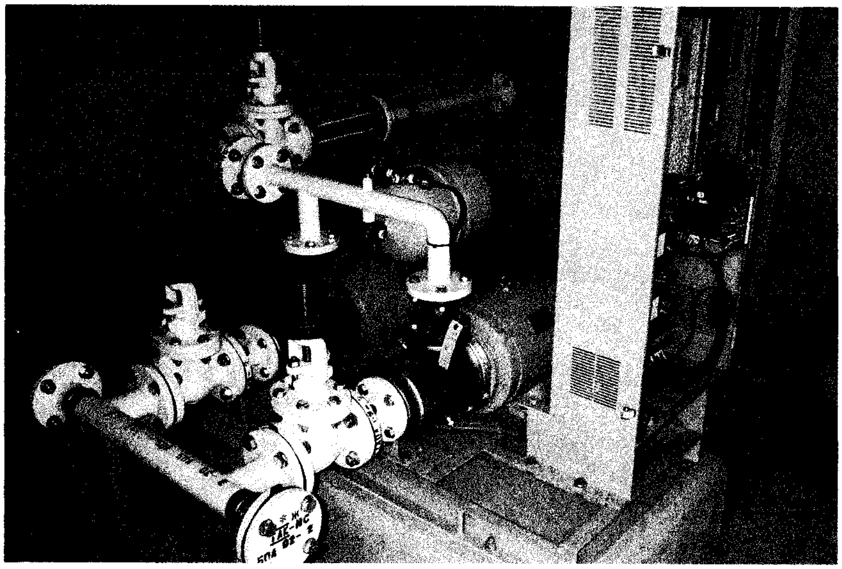

Figure 50 View of Variable-Speed Motors and their Loads

In this case the controller injected switching impulses onto the building wiring, the impulses were conducted to an outside pole transformer, passed through the transformer and onto the overhead distribution line conductors. Radiation from the overhead-line conductors caused radio noise at a receiving site located several km away.

Figure 51 shows the controller used to convert direct-current voltage from solar cells into alternating current at the frequency of the power provided by an electric utility. In this case the controller was used in a residence where solar-generated electricity was used to supplement power from the electric utility serving the area. High levels of switching impulses were injected onto the conductors running from the controller to the roof-mounted solar cells, and radiation from these conductors resulted in severe noise to a receiving site located more than a km from the source.

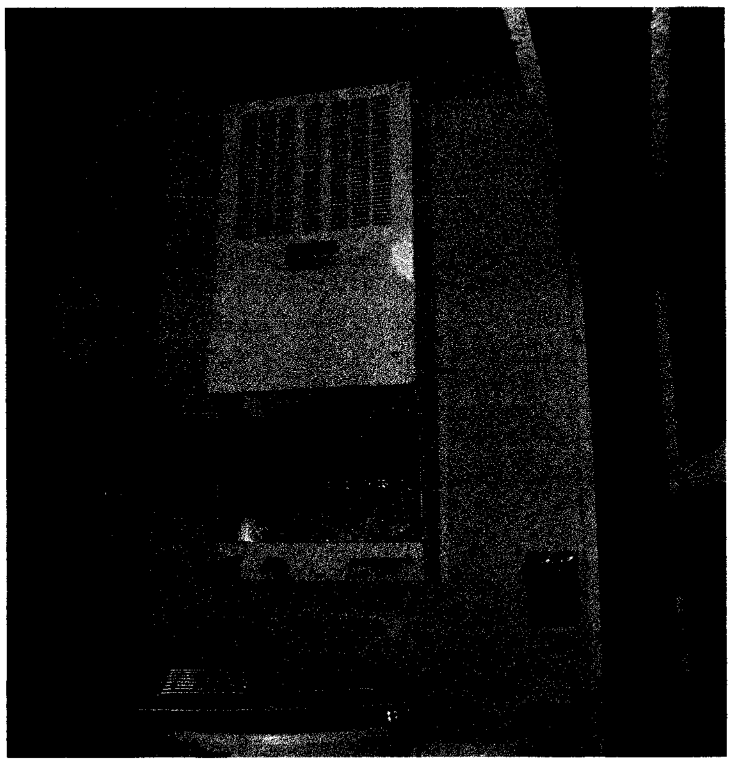

Figure 51 Solar Power Converter

The controller shown in Figure 51 did not contain a FCC Class A or B label. Because of this it was a unit improperly marketed in the United States. This particular model is no longer available, but it raises questions about similar units that are built with no consideration of man-made radio noise or of units built to FCC Class A specifications that find their way into residences. Several complaints of radio noise from such devices have been reported, and in most cases the resident had insufficient knowledge and background to understand the implications of the noise ratings.

Figure 52 shows a controller and three induction motors used to control the flow of enriched water to plants in a hydroponics farm located about 11 km from a receiving site. The controller is shown in the top view and the three motors it controls are shown in the bottom view.

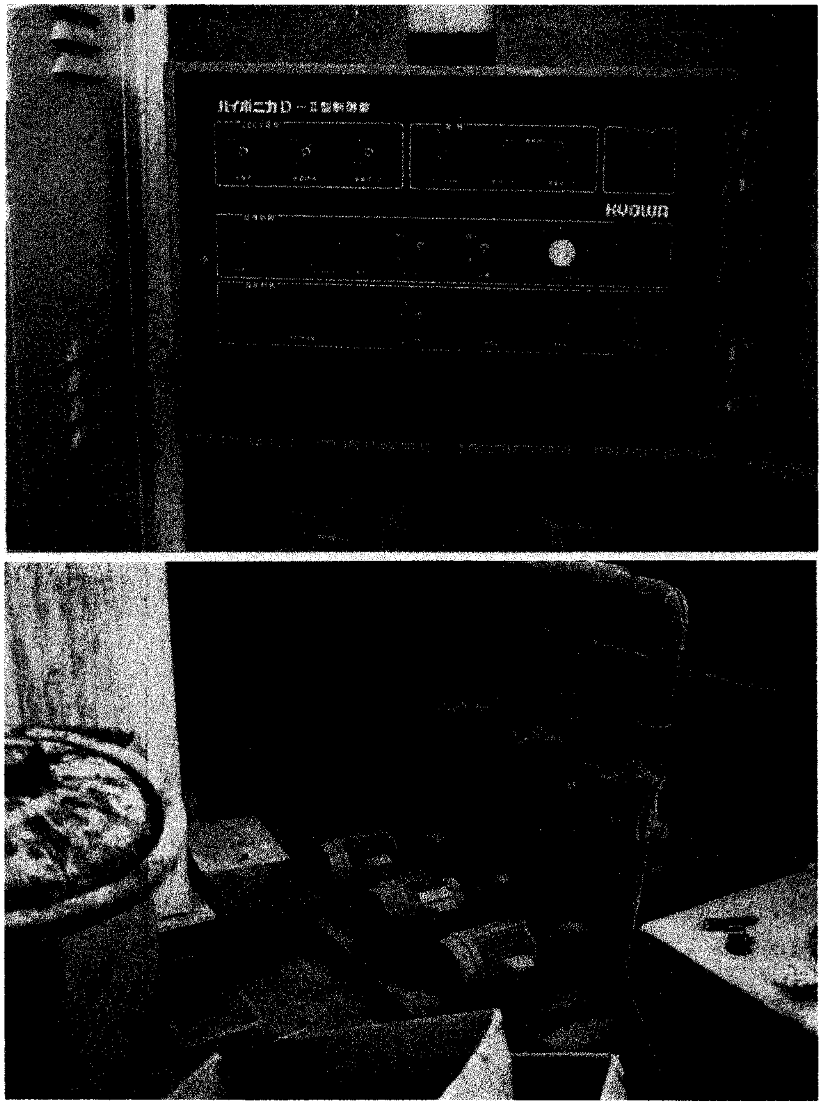

Figure 52 Motor Controller at a Hydroponics Farm

Figure 53 shows the external electric power feed into the building containing the hydroponics farm. The controller was located inside the building on the inside of the wall shown in photograph. The power drop was connected to an overhead pole transformer located about 30 meters from the building, and the overhead line feeding electric power to the transformer ran along the road in front of the building. Controller-generated radio noise radiated from the overhead distribution line.

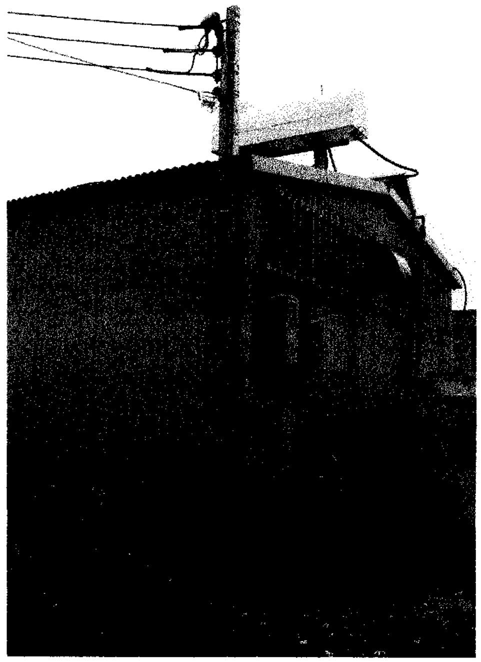

Figure 53 Power Feed for Hydroponics Farm

Figure 54 shows the conveyor belt associated with a machine used to sort, process, and prepare flowers for shipment to sales outlets. The speed of the conveyor belt is controlled by a solid-state variable-speed motor controller. The enclosure housing the power-conversion electronics is the grey box under the belt and to the left of the seat of the motorcycle that was parked in the facility. The motor is located under the belt and is not visible in this photograph.

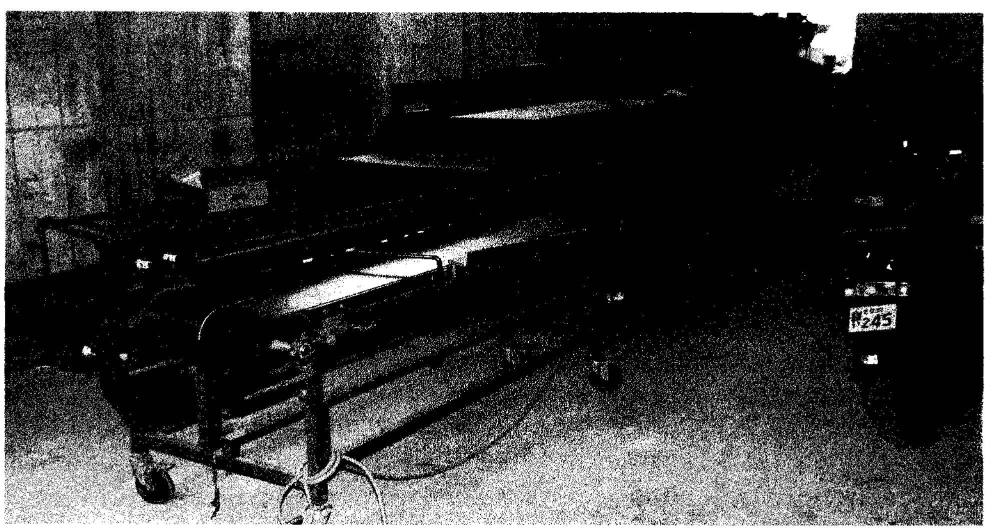

Figure 54 Photograph of Flower Processing Machine with Variable-Speed Drive

4. Step 3—Locate Sources

4.1 Power Line Sources

The location of sources on power lines must be done only by individuals trained in the hardware and safety aspects of working around overhead distribution lines. Carefully read the following warning and comply with all aspects of the warning.

WARNING

Individuals following the field procedures in this section are cautioned that electrical shock hazards, including possible electrocution, exist when working near and around power lines. All personnel working near power lines must use due caution and work under the supervision of trained personnel and be provided with the appropriate safety equipment. Inexperienced personnel should not attempt to work on or near power lines.

The procedures described herein do not require the attachment of instruments or probes directly on power lines. Furthermore the procedures in this document do not require that poles, guy wires, or other conducting objects be touched or moved. This includes striking poles with sledges, mallets and other objects. These and similar actions are specifically excluded as they are dangerous, and they do not produce useful results.

All field personnel and support personnel are cautioned that guy wires, switch handles, damaged ground wires, and other conducting objects may be at high potentials due to leakage, insulation failure, or reactive coupling effects. Stay clear of pole hardware and stand clear of line conductors during noise mitigation work. Be alert to possible mechanical failure, particularly on older lines.

WARNING

Most sources of power-line noise are associated with electrically small metal objects. Thus, direct radiation from the actual source hardware is usually insufficient to account for the reception of such sources at a receiving site; however such sources inject significant levels of noise current into overhead-line conductors, ground conductors, guy wires, and other nearby electrically-long conductors. Radiation of noise from these conductors, rather than direct radiation from the noise source, is a primary aspect of the power-line-noise problem.

Figure 55 shows a block diagram of the factors involved in the reception of power-line noise at a receiving site. Each block in the diagram has electrical characteristics that vary with frequency. A microspark or spark produces spectral components over a very wide portion of the radio spectrum; often up to 1-GHz. Usually the microspark or the spark is not directly connected to the overhead power-line conductors. The electrical properties and dimensions of conductors associated with the source and the capacitive and inductive coupling of the spark to nearby conductors along with the electrical dimensions of these conductors distort the spectral shape of the noise and result in peaks and nulls in its spectral shape. The electrically-long power-line conductors carrying and radiating noise also have significant impedance variations with frequency, and the lobes and nulls of their radiation patterns vary in direction and magnitude with frequency. The propagation path from the radiating power-line conductors to the receiving-site antenna often contain conducting objects such as buildings, trees, other overhead lines, and other conducting objects that introduce frequency-sensitive distortion to the noise. Finally, the lobes and nulls of the receiving-sites' antenna in the direction of a source also change with frequency. All of these factors have a significant impact on the fine-scale and the coarse scale spectral shape of broadband impulsive noise observed at the input terminals of a site's receiver as well as producing smaller changes in the temporal structure with frequency. While these factors complicate the job of precisely defining the spectral and temporal properties of noise observed at a receiving site and relating it to a source, an understanding of the general impact of the various factors on the temporal and spectral properties of noise is essential for the conduct of successful source-location work. The spectral shape of noise observed at a receiving site is much different than the spectral shape of noise observed at or near a source.

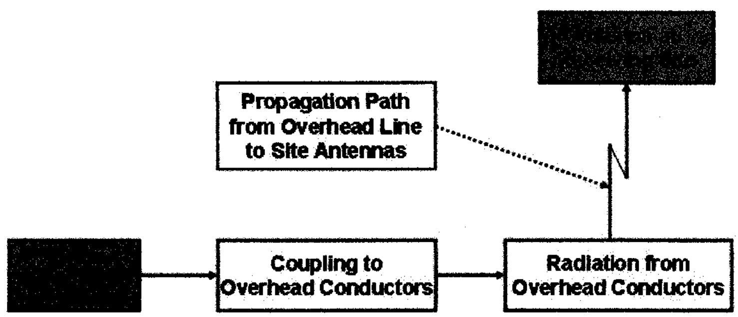

Figure 55 Block Diagram of Source-to-Victim Path

The source-location techniques described in this handbook are based on the distance noise current is conducted along a power line as frequency is varied, and the radiation of noise from these conductors. At low HF frequencies, noise current flows for relatively long distances along the overhead conductors of a power line. At high VHF and low UHF frequencies the amplitude of noise current on a power line decreases rapidly with distance from a source.

Figure 56 illustrates this effect. The time-history view shows noise exceeding a threshold level as a spectrum analyzer and its time-history display are moved along a power line at constant speed. The location of two poles, both containing sources, is shown on the left edge of the time-history view. The poles are about 30-meters apart. At low VHF frequencies (and also at HF frequencies not shown on this example) high levels of noise exist over the entire distance traveled, but at high VHF frequencies, noise is detectable only when near the pole. As a general rule, the higher the frequency the nearer one must be to a source for the noise to exceed a threshold. Thus a portable receiver with an AM detector, a relatively wide IF bandwidth, and a tunable frequency range from HF up to about 1000 MHz is a primary tool for source location.

The data shown in Figure 56 suggests that noise sources on distribution lines built along roads can be located simply by installing a HF/VHF/UHF receiver in an automobile and driving along the road. This indeed is a practical way of locating the general region of a source, but the excessive impulsive noise from the ignition systems of many gasoline-powered automobiles makes it difficult to locate similar impulsive noise from power-line sources. Modern diesel-powered vehicles often radiate excessive impulsive noise from their fuel injection and other digital systems. It is essential that source-location teams use radio-noise-quiet vehicles.

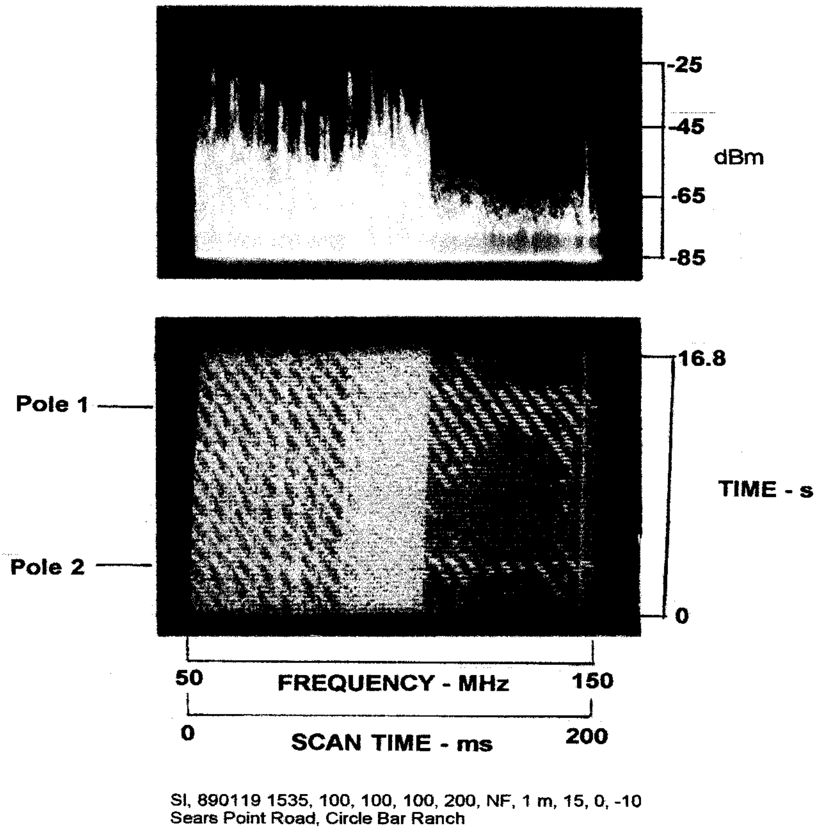

Figure 56 Variation in Spectral Content with Distance from Sources

Two battery-operated and portable receivers specifically designed for the investigation of radio noise from power lines have been developed for use by electric-utility personnel. They are the Models 240 and 242 MF/HF/VHF/UHF RFI Locators provided by Radar Engineers of Portland Oregon (radarengineers.com). The receivers can be used with a noise-quiet vehicle to search for sources on distribution lines that are located along roads. A 1-meter magnetic mount antenna on the roof of the vehicle can be used to receive noise. When the general region of a source is located, multiple passes with the receiver tuned to higher and higher frequencies may be necessary to pinpoint a source. Subsequent refinements in the final location on foot are often required to ensure that the correct pole or tower is located.

Figure 57 shows two photographs of the Model 240 RFI Locator during a source-location task. In the left view a small rod antenna is used while the receiver is carried along a power line. In the right view the receiver is used with a hand-held log-periodic antenna to determine the direction to a noise source. In both cases one must start at a frequency in the low VHF range and successively use higher frequencies to pinpoint the location of the source.

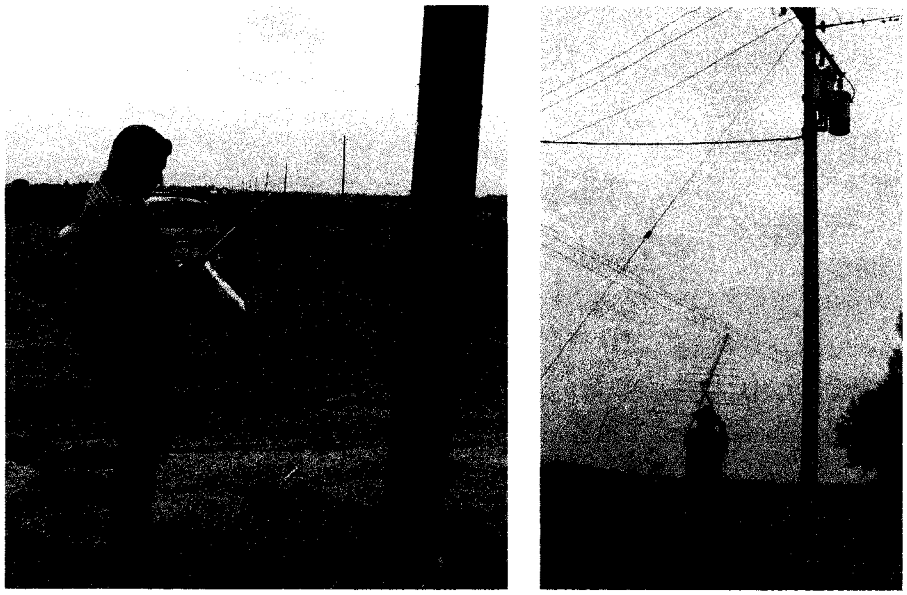

Figure 57 Source-Location Using the Model 240 or 242 Locator

The display incorporated into the Radar Engineers Models 240 and 242 receivers is highly useful during source-location work. Its presentation of the temporal structure of noise from a nearby source enables the external team to compare the structure and activity to that observed at a receiving site. Figure 58 shows an example of the temporal structure of a source under investigation at a receiving site. The signal-strength meter is shown below the display along with other controls.

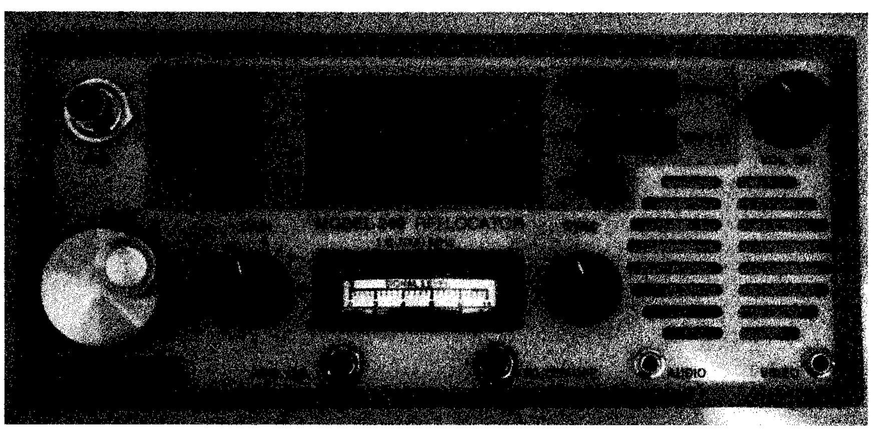

Figure 58 Temporal Display on Model 240 Receiver

Other hand-held receivers with similar frequency coverage are available from suppliers of communications equipment. Examples are the models IC-R5, IC-R3, IC-R10, and IC-R20 from ICOM (see icomamerica.com), the model TH-G71A from Kenwood (see kenwood.net), and the model AR-8200 series from AOR U.S.A., Inc (see aorusa.com). While these are excellent communications and general-purpose receivers, their narrow IF bandwidths and lack of a display of the temporal structure of noise make them less desirable for source-location work.

Still one more technique can sometimes be used to locate poles containing noise sources. Figure 59 shows a Model 240 RFI Locator on a hilltop overlooking a distribution line. The log-periodic antenna is pointed at the distant distribution line and slowly scanned along the line for noise. Poles on the distant line must be visible from the hilltop. Repeated scans at higher and higher frequency will allow sources on individual poles to be located by this technique with the RFI Locator at distances up to about 1 km from a distribution line.

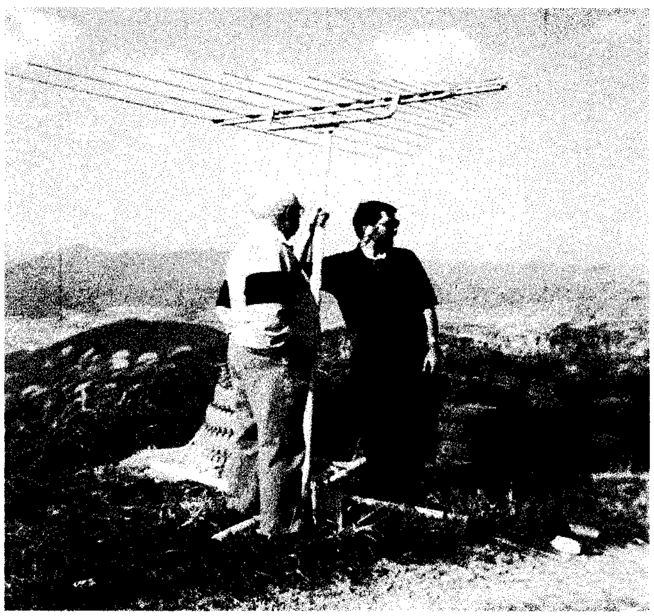

Figure 59 Hilltop Source Location with RFI Locator

A standard battery operated HF receiver is often useful during source-location work. It can be used to monitor the activity pattern of erratic sources for correlation with the activity pattern observed in the receiving site while the RFI Locator is moved from one location to another. A Sony Model IC 2010 or any equivalent portable HF receiver can be used for this purpose. Some portable receivers have an RF gain control which is useful to avoid overloading. Alternatively, the length of the antenna can be shortened to reduce overloading problems.

As source poles are located, a portable GPS is used to determine the location of the source, the direction of the source from the receiving site, and the distance from the source to the site. This information is entered into a source-location log along with other comments. Table 3 shows a suggested source-location log.

Table 3 Source-Location Information

Site ________________

Source Identification No. ______________

Date _____________

Time ____________

Pole ID ________________

Location ____

Latitude ______________

Longitude ____________

Site-to-Source Bearing ______________

Site-to-Source Distance ______________

Noise Description ____

____

Comments ____

____

Source Hardware ____

Mitigation Actions ____

____

____

____

____

Note: The last two items in Table 3, ***Source Hardware and Mitigation Actions****, cannot be completed until the source hardware is identified. These items are included in the table to permit all information about each source can be recorded in one place.*

Table 4 lists the power-line source-location equipment used to obtain the information needed to produce this handbook.

Table 4 Source-Location Equipment

Item	Model No.	Source
RFI Locator	Model 240 or 242	Radar Engineers
HF Receiver	IC 2010 or eq.	Sony
Log Periodic Antenna	CLP 5130-1 (50 to 1300 MHz	Create
Log Periodic Antenna	CLP 5130-2 (108 to 1300 MHz)	Create
Loopstick Antenna	1700 to 6000 kHz Frequency Range	Palomar Engineers
Whip Antenna	1-meter magnetic Mount	Larson
Short Antenna	14 to 20 inch with BNC	Centurion
GPS	Several Types are Available	
Communications Equipment	As needed for each task	
Noise-Quiet Automobile		Local Rental

A sources-location team must always receive timely information about the activity patterns and the temporal structures of the most harmful sources as determined by real-time measurements within a receiving site. This requires real-time coordination between the internal noise-measurement team and the external source-location team. This coordination can preferably be provided by a dedicated radio link. Alternatively, cellular telephones can be used at locations where such service is available, although with considerably less success because of the need to maintain continuous voice communications over long time periods. It is also useful to pass audio sounds of received noise between the internal and external teams over a radio link, and the narrow audio-frequency range of cellular telephones severely limits their usefulness. In addition, the use of communications devices at or near a source-location effort must ensure that radio interference does not adversely affect the source-location team's efforts. It is essential that all communications equipment employs frequencies well above the upper-frequency limit of the equipment used by the external source-location team.

A detailed knowledge of the various fine- and coarse-scale temporal structures described in Section 2 and of typical real-time activity patterns of many kinds of sources is required by personal of both the internal and the external teams. Any attempt to conduct source-location work without fully trained and qualified personnel will only result in lack of success, frustration, and disappointment in the paucity of results.

4.2 Power-Conversion Sources

Procedures for the location of power-conversion sources are similar to those used for the location of sources on power lines with one major exception. Most power-conversion sources do not radiate sufficient energy above the HF band to use the VHF and UHF frequencies to obtain direction from a site to sources or to locate sources. Because of this, two sequential techniques are used to locate such sources.

4.4.1 Step A

The first step is to use an elevated HF loop-stick antenna at the site along with a Model 240 or 242 RFI Locator. The loop stick and RFI Locator are both tuned to a frequency that maximizes the noise amplitude, and the loop stick is rotated until a null is reached off the end of the antenna. Alternatively, a maximum off the side of the antenna can be used. Either will provide bi-directional information from the site to the source. A review of facilities and potential sources in the two opposite directions will often place emphasis on only one of the directions.

Figure 60 shows a commercially available loop stick antenna mounted on a tripod to obtain direction to a power-conversion source located in a residential area. In this case a tunable loop stick built for use at the low end of the HF band was used. A Model 240 RFI Locator is shown below the antenna, and it shows the temporal structure of noise from a power-conversion device on its display. If multiple sources exist, they can easily be sorted because of differences in their temporal structures, and the direction to each source can be determined. While some practice is needed to find the null off the end of the loop stick or the maximum off the side of the loop stick, the technique can be highly effective in determining the direction to sources.

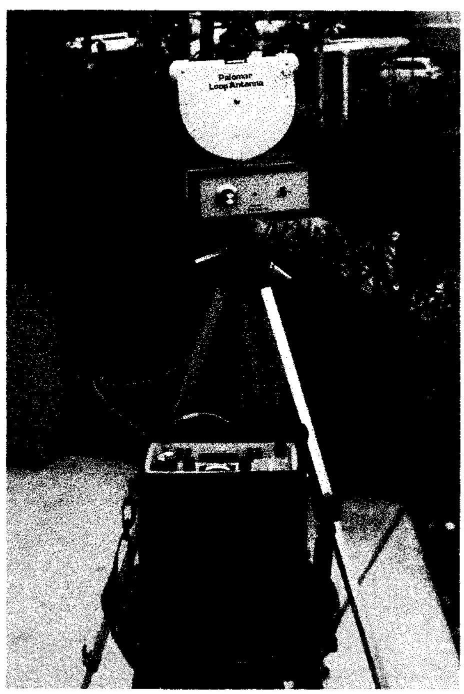

Figure 60 Loopstick Antenna for Location of Power-Conversion Sources

4.4.2 Step B

The second technique is the use of a broadband HF loop stick antenna mounted on the roof of a noise-quiet vehicle and connected to a Model 242 RFI Locator. Modest increases in noise level will occur as a power-conversion source is approached since high levels of higher-order harmonics of the power-line frequency (along with other spectral components developed by most power-conversion devices) can be detected for hundreds of meters along an overhead power line. With proper design, the loop stick can be made insensitive to low-order harmonics produced by many other sources of little interest. This technique will locate the general vicinity of a power-conversion device. The temporal structure of the noise can be observed on the display of the Model 242 RFI Locator and compared with that observed inside the site.

Figure 61 shows a photograph of a medium-frequency loop stick on the roof of a search automobile along with a Model 242 Noise Locator and held in place with a magnet. The loop-stick is normal to the power line as the vehicle moves along a road to maximize its sensitivity to radiation from the power line. A Model 242 RFI Locator is in the vehicle where its display and audio output can be monitored.

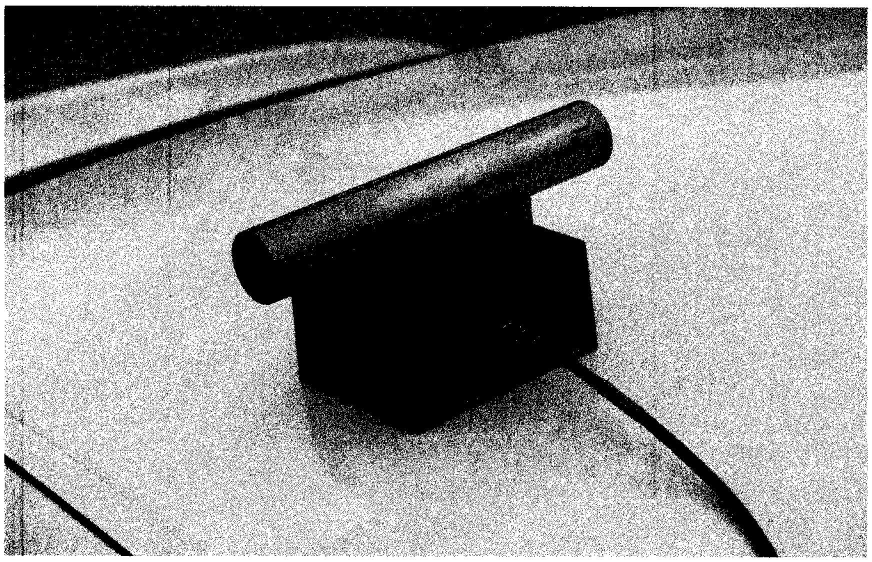

Figure 61 Loopstick Antenna on Roof of Source-Location Automobile

Once the general location of a power-conversion source is determined, the noise from the higher-order harmonics and other spectral components can be examined on the secondary side of each pole-line transformer in the vicinity. The highest noise level will be found on the secondary which provides provide power to the facility containing the power-conversion device.

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5. Step 4—IDENTIFY SOURCES

5.1 Distribution Line Hardware

The identification of specific items of hardware on power poles requires working close to high voltage components. The following warning must be strictly followed during the conduct of source-identification work.

WARNING

> **Individuals following the procedures described in this handbook are cautioned that electrical shock hazards, including possible electrocution, exist when working near and around power lines. Inexperienced personnel should not attempt to do source-identification work. This part of the radio-noise-mitigation effort must be accomplished by personnel trained to work on hot lines or by utility-trained lineman. All instrumentation must be suitable for use on and near hot lines. Do not assign untrained personnel to this task.**

WARNING

The Radar Engineers Model 247 Noise Sniffer is used by the authors and their associates as well as by many electric utilities. It is mounted on the end of a distribution-line rated hot stick. Figure 62 is a view of the instrumentation and equipment used for the identification of pole-line hardware containing noise sources.

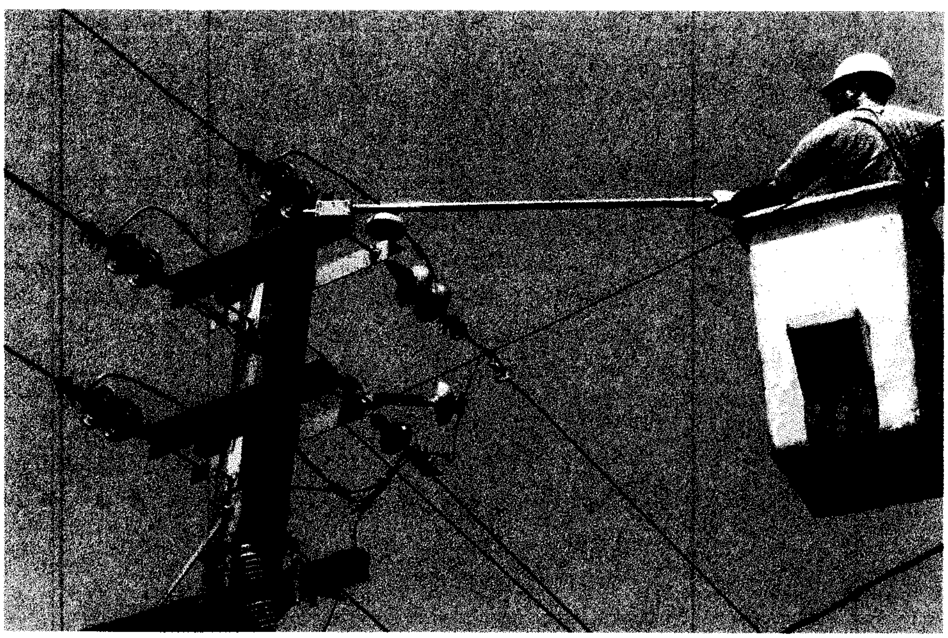

Figure 62 Source Identification with a Noise Sniffer

The noise sniffer is fastened to the end of the hot stick and is simply moved around the hardware on the pole until the strongest signal is obtained. This can best be accomplished by elevating the noise sniffer operator to the vicinity of the hardware with a utility-rated bucket truck. In the example shown in Figure 62, the source is located on the clevis pin between two sections of a bell. Never use an ordinary bucket truck designed for general construction work or for telephone line work since these are not insulated for operation near high voltages.

Source activity should always be monitored in the site and also on the ground near the source during sniffer work. The RFI locator receiver described previously or an HF portable receiver can be used for such monitoring. Use a short rod antenna (14" to 18" in length) on the RFI locator when close to an active source.

The Model 247 Noise Sniffer contains both RF and acoustic sensors. The RF sensor is usually the most effective sensor for work on distribution lines because many sources produce little or no useful acoustic noise. In addition, many sources are acoustically isolated from the external regions of hardware. In some cases where the source is very strong, or when a sparking source exists on the outside surface of hardware, the acoustic sensor is useful.

Sometimes the temporal structure of the noise (observed inside the site and confirmed by outside observations) is sufficient to suggest the type of hardware generating the noise. A highly experienced person can sometimes identify hardware by this process. This process requires considerable field experience and a detailed knowledge of a very large number of possible source mechanisms, and this method of hardware identification must be used with great caution.

In principle, the source-identification process is straightforward. In practice, several pitfalls complicate the process. Sometimes a source cannot be located on a specific pole. When this happens, check adjacent and nearby poles to ascertain if the adjacent pole impedance effect (see Section 4.1) has confused the source-location process. In addition, check all hardware such as switch handles, ground conductors, guy wires, braces, and other possible sources that may be nearby (see list of sources in Tables 1 and 2). Another pitfall is the presence of multiple sources on a pole. In such cases, all sources on a pole should be eliminated by effective mitigation actions.

There can also be cases where noise is conducted onto an overhead line from an underground line. In such cases, underground-to-overhead cable heads should be on the pole. A source on the underground line can be differentiated from sparking at a faulty cable head with the RF and acoustic sensors. If the acoustic sensor indicates a source, it probably will be from a sparking cable head. If the RF sensor indicates a source of noise at the cable head and the acoustic sensor does not, the source probably is on the underground line.

Still another problem is that the operator of the sniffer must have knowledge of a wide variety of pole-line hardware. In addition, the operator must know what hardware can generate radio noise, the noise-source mechanisms, and what replacement hardware can be used to eliminate each individual noise source.

Still one more technique is available for identifying source hardware. An ultrasonic dish is available from Radar Engineers that is effective at identifying the hardware associated with some sparking sources. Figure 63 is a photograph of the Model 250 Ultrasonic Parabolic Pinpointer pointed at a sparking source on a pole. It can detect radio noise from sparking sources from the ground as long as the source is in line of sight of the dish. Thus, it is useful to walk around a pole suspected of containing a sparking source to maximize noise detection and source identification.

While the Ultrasonic Pinpointer is primarily useful in identifying sparking and corona sources on transmission lines, its small size and light weight of the device make it very useful to carry along overhead distribution lines for preliminary searches for sparking sources.

Figure 63 Ultrasonic Parabolic Pinpointer

While the ultrasonic sensor provides an excellent means to detect and identify hardware with sparking sources that are in line of sight, it cannot detect many micro-sparking sources that emit little or no acoustic energy. It is excellent auxiliary tool, but it must be used with care and with other sensors capable of detecting and finding micro-sparking sources such as those associated with bell insulators, insulated tie wires, and lightning arresters. Also, the sensor cannot provide information about the temporal structure of a noise for comparison with the properties of noise affecting the reception of radio signals from a receiving site.

The combination of the Model 250 Parabolic Pinpointer, the Model 240 or 242 RFI Locator, and the Model 247 Sniffer provides a comprehensive means to identify noise-generating hardware on power lines.

Table 4 lists the source-identification instrumentation used by the teams participating in the field work that supported the information provided in this handbook.

5.2 *Identification of Power-Conversion Sources*

Once the facility containing a power-conversion device is located, identification of the actual hardware generating the noise is often a matter of visual inspection of the facility. This is especially the case for individuals familiar with such power-conversion. Nevertheless, verification of the actual source is recommended. Several options are available to the source-location team. They are:

5.2.1 Technique A

Scan all circuit breakers at the electric-power panel of a facility with a circuit sniffer. The Radar Engineers Model 245 Circuit Sniffer is an effective instrument for this task. It will locate circuit breakers feeding power to devices that generate wide-band radio noise.

Figure 64 is a photograph of the Model 245 Circuit Sniffer in use at a small facility where a switching power supply on a fiber-to-wire converter caused radio interference to a nearby receiving facility. The circuit breaker carrying radio noise was quickly identified and its conductors were traced to the offending source of noise. Turning the power-supply off at the converter verified it was the source of the noise.

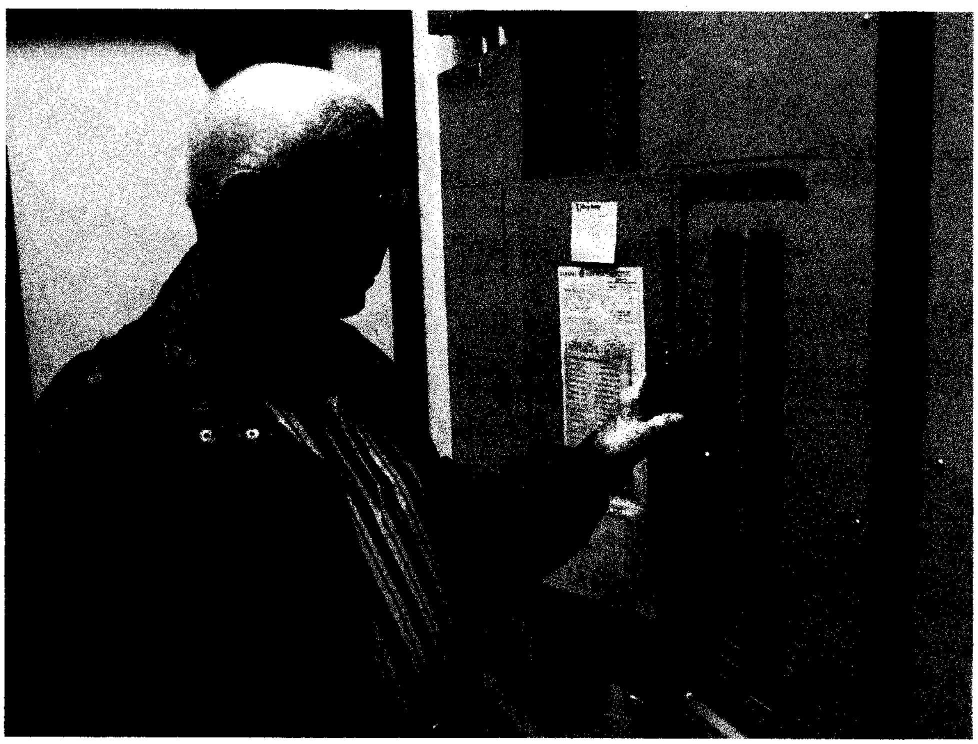

Figure 64 Using the Model 245 Circuit Sniffer

5.2.2 Technique B

The Radar Engineers Model 242 RFI Locator is an excellent instrument to sniff a facility for sources of radio noise when it is equipped with a small antenna or an RFI-locator probe. This instrument allows the RFI investigator to observe the temporal structure of noise and compare it with the temporal structure observed at a receiver site. This capability is highly useful in source-verification tasks.

Figure 65 shows the Model 242 RFI Locator in use with a loop stick antenna to identify conductors associated with a power-conversion device that carry excessive levels of EMI current. The conduit near the loop stick carried significant levels of broadband conducted noise current from a variable-speed motor drive located to the rear of the operator. This instrument and the similar Model 240 RFI Locator have also been used with other antennas and probes with excellent results.

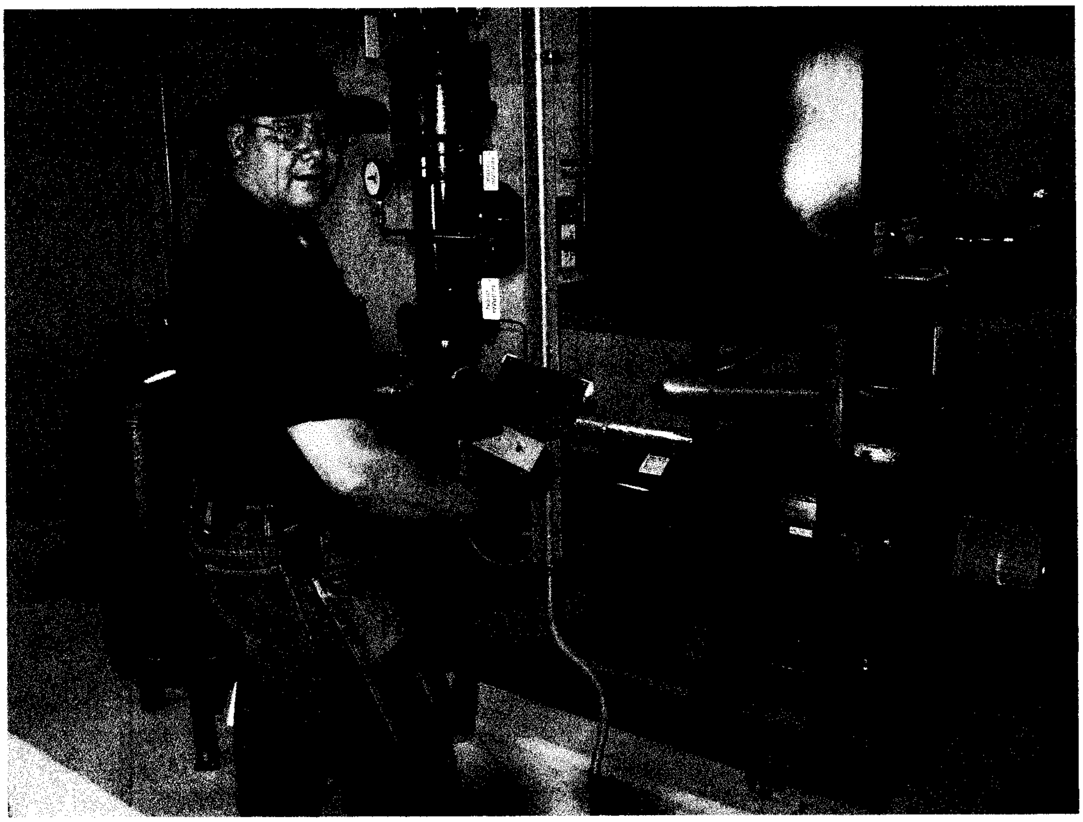

Figure 65 Using the Model 242 RFI Locator and Probe

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6. Step 5—SOURCE MITIGATION

6.1 Power-Line Sources

Distribution power lines constructed in accordance with the information provided in Appendix A rarely contain a source of radio noise. Such lines have been constructed on a trial basis, and all were completely free of noise sources for many years. However, most distribution lines are constructed in accordance with the practices and hardware of each electric utility, and radio noise problems are rarely a consideration in such construction. It is then necessary to locate each source of noise and identify each item of hardware generating radio noise that adversely affects signal reception at a receiving site. Practical and successful mitigation procedures are described in this section.

6.1.1 Bell Insulators

Clips and brushes have been designed to be inserted into the clevis of a Bell Insulator. Either one provides a conducting path between the metal parts of the insulator thus preventing the build up of charge across oxide layers that form on the surface of the metal parts. These devices provide a temporary means to prevent the operation of the noise source, but with time they become loose from the almost continuous movement of the line conductors, the bell, and other components of a distribution line. The clips and brushes eventually loosen and fall out. The noise then reappears. Since clips and brushes do not provide a long-term solution their use to correct noise problems at a radio-receiving site is not recommended.

Figure 66 shows a clip and a brush. They are manually inserted into the clevis connecting the metal parts of a bell. Both are made of stainless steel to deter corrosion from weather exposure.

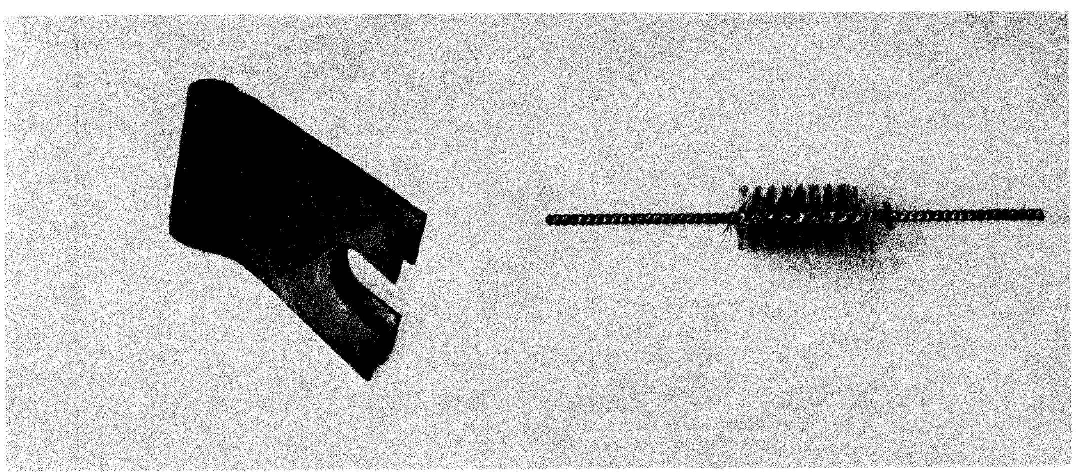

Figure 66 Clips and Brushes

Usually utility personnel will replace a noisy bell with a new bell insulator, but a replacement bell insulator will often become a source of noise after a short period of use. Thus, never replace a bell insulator found to be a source of noise with another bell insulator.

The only effective mitigation action is to replace a bell insulator identified as a source of radio noise with a polymer insulator. Furthermore replace all bell insulators on a pole containing a noisy bell with polymer insulators. This is the only effective way to eliminate bell-related sources.

Figure 67 shows an example of a polymer insulator. Variations will exist in the configuration of a polymer from one model to another, but all contain a fiberglass rod covered by a weatherproof polymer material. Metal components on each end of the insulator are attached by compression onto the fiberglass rod. Since the end-to-end capacitance of a polymer insulator is extremely low, sufficient charge cannot accumulate on the metal components at the ends of the insulator to support a microspark type of noise source.

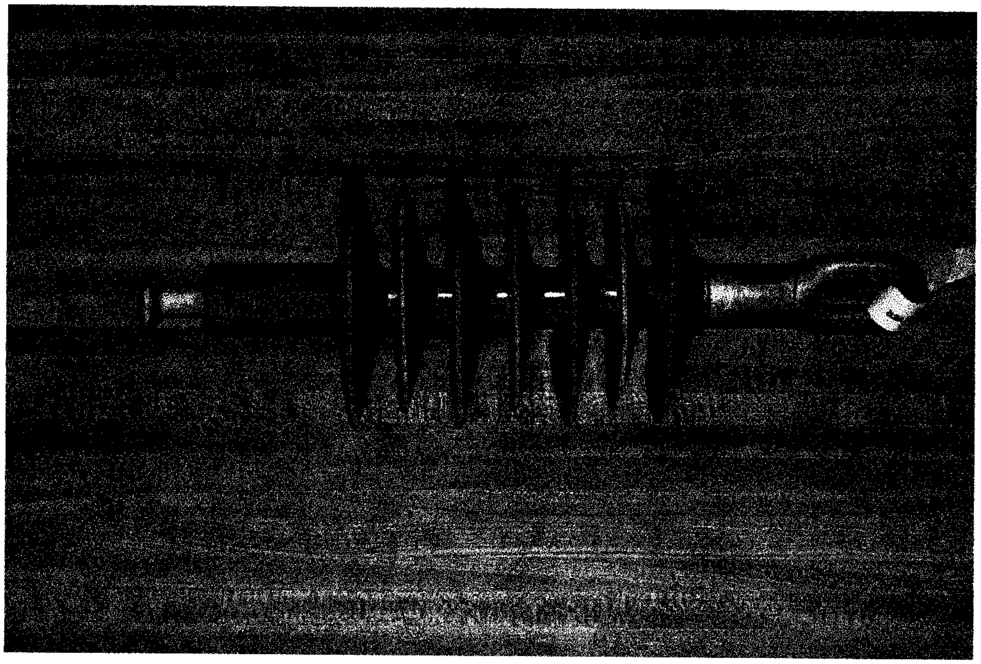

Figure 67 Example of a Polymer Insulator

6.1.2 Sparking Sources

Sparking sources are caused by the breakdown of air between two closely-spaced metal objects or between a metal object and a plastic component that has accumulated a surface charge. Metal components can be bonded together and grounded to earth. This prevents a voltage difference between components. Alternatively, all metal components on a distribution line can be separated by at least 1½ inches. These two actions will eliminate sparking sources associated with hardware.

6.1.3 Tie Wires

A variety of ways to use tie wires exist. In the United States most distribution-line conductors are not insulated. Usually bare tie wires are used on bare line conductors. This results in the tie wire and the conductors being at the same potential. Thus, microsparking or sparking cannot occur. However, if the tie wire is poorly and loosely wrapped around the conductor and the insulator, the rubbing between the tie wire and the conductor can result in a noise source. This kind of source is relatively rare and can be corrected by replacing the loose tie wire with a tightly wrapped tie wire.

In may countries and in some isolated locations in the United States, the conductors of a distribution line are insulated. Thus, a potential difference can exist between the line conductor and either a bare or an insulated tie wire. A nearby lightning strike or a nearby radio transmitter can induce a voltage on the line conductor and further increase the potential difference between the tie wire and the line conductor. Eventually, the insulation on the line and/or on the tie wire will start to break down. The breakdown usually starts at the end of the tie wire or at a sharp bend in the tie wire where impedance effects result in high potentials similar to the high potential that exists at the ends of an antenna. Once the insulation breakdown process starts, carbon deposits caused by the small intermittent arcing can result in a noise source.

Utility personnel usually replace a damaged tie wire with a new tie wire. This is only a temporary solution since the process that initiated the original arcing is often repeated. The only effective way to permanently eliminate such a source is to eliminate the potential difference between the tie wire and the line conductor. Figure 68 shows a method of eliminating the potential difference where the tie wire is electrically connected to the line conductor with a bronze cable clamp. In this example an insulated tie wire is used on an insulated line conductor. A short portion of the insulation on both the tie wire and the line conductor was stripped to allow the bronze cable clamp to be attached to both conductors.

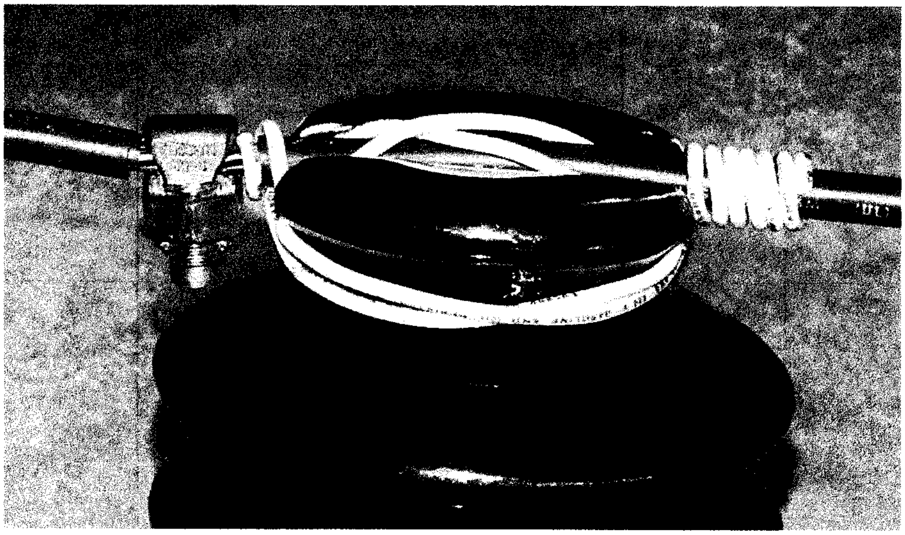

Figure 68 Tie Wire Source Mitigation, Example 1

Figure 69 shows another example where the tie wire is electrically connected to the line conductor. In this example, a bare tie wire is used on an insulated line conductor. The line conductor was stripped of its insulation where it was attached to the insulator.

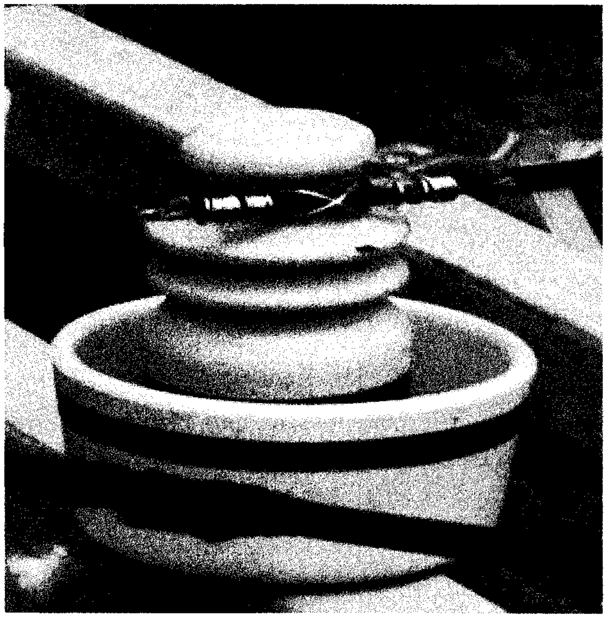

Figure 69 Tie Wire Source Mitigation, Example 2

6.2 Power-Conversion Sources

It is impractical to provide specific mitigation instructions for each of the many sources of radio noise associated with power-conversion devices. Small devices can often be mitigated with minimal changes and at low cost. Large devices often require considerable modification at high cost. The general approach is identical to all such sources, and this section describes the procedures needed to eliminate radio noise from power-conversion sources.

The best approach is to ensure that the procurement of any equipment or system containing a power-conversion device meets the Class B radio-noise requirements of the Federal Communications Commission of the United States or similar requirements in other countries. Devices that meet the Class A radio noise requirements of the Federal Communications Commission or similar requirements of other countries should never be used within line-of-sight of an HF, VHF, or UHF receiving site. In addition, power-conversion devices that are not rated must be avoided.

Since a receiving site often cannot control the installation and use of electronic devices in other facilities located within line of sight, the source-location and source-identification procedures described in Section 4 must be followed. The basic mitigation process and techniques are described in this section.

After a power-conversion source is located and identified, it must be inspected to determine the best approach to control the coupling of radio noise from the source onto power, conduits, ground conductors, and other conductors associated with the operation of the source. The actual source of impulsive current and voltage must be placed inside an electromagnetically shielded enclosure and all impulsive current and voltage on conductors entering or exiting this enclosure must reduced to harmless levels. This can be a small enclosure for a physically small source or it can be a large shielded room for a physically large device.

Figure 70 shows the start of this process where the source is completely enclosed within an electromagnetic barrier.

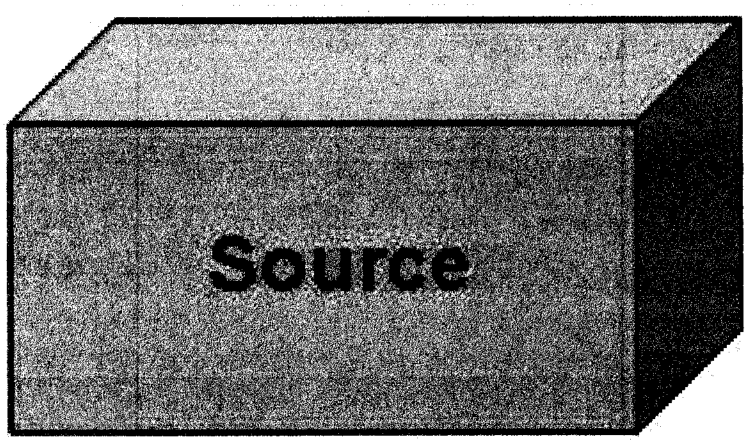

Figure 70 Source Enclosed within an Electromagnetic Barrier

Figure 70 describes a somewhat impractical case since power must be provided to the source, a ground must be provided, the source probably will be connected to other devices, and conductors are often required to control the operation of the source. Figure 71 shows how power can be applied to a source. A filter can be installed directly onto the metallic surface of the enclosure and power can be provided through the filter. The filter allows electric power to be provided to the source at low loss while the higher-frequency noise is attenuated and cannot be conducted onto the outside power conductors. Small and inexpensive filters can be used on low-power sources, but large filters will be required for high-power sources.

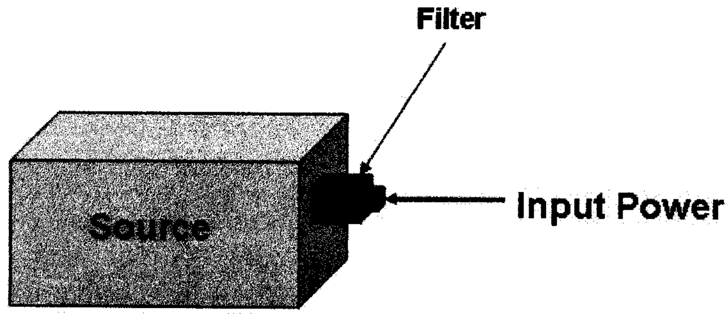

Figure 71 Provision of Power to a Source

Most sources operate an external device. For example, many sources operate variable-speed induction electric motors by varying the frequency of the power provided to the motor. A second filter can be installed on the surface of the electromagnetic barrier to prevent the conduction of noise current and noise voltage to external conductors. Alternatively, the electronic barrier can be extended to include the conductors from the barrier to the motor. Most electric motors are sufficiently enclosed in metal to provide a suitable electromagnetic barrier. Figure 72 shows such a configuration where conduit is used between the source and the motor or other load to shield the conductors. The conduit must be electrically bonded to the source barrier and to the metal barrier enclosing the motor or other load.

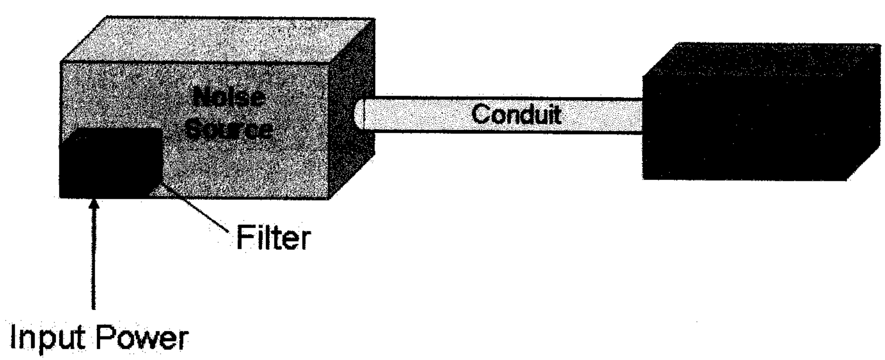

Figure 72 Source-to-Load Connection

Most electrical and electronic installations require a safety or green-wire ground. Ground conductors can carry significant amounts of noise current and voltage (often higher levels than the power conductors), and they must also be controlled. Figure 73 shows an effective means to prevent the conduction of noise current and voltage from a source to an outside conductor over a ground wire. Ground conductors inside the barrier are bonded to the inside surface of the barrier. Ground conductors outside the barrier are bonded to the outside surface of the barrier. This provides a path for noise current flowing on the internal ground conductor to return its source inside the barrier while the barrier provides a shield that prevents the conduction of noise current and voltage to the outside ground conductor. Since the barrier will conduct low-frequency power-related current, all safety aspects of the green-wire ground are maintained.

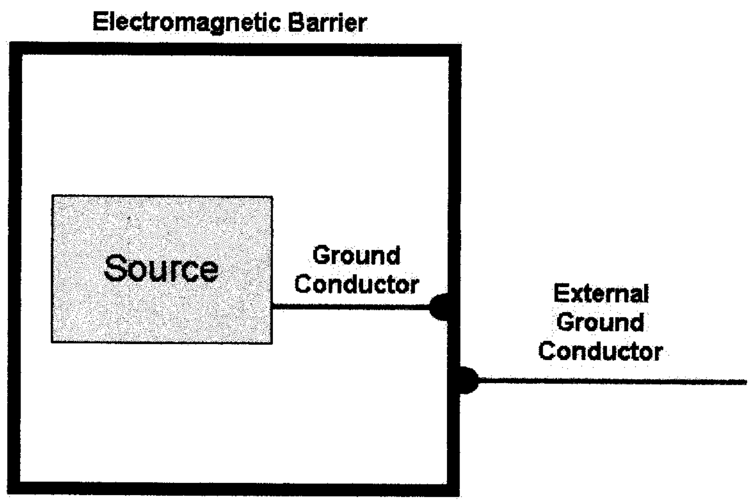

Figure 73 Barrier Treatment of Ground Conductor

Additional filters can be provided on the surface of the barrier to permit control wires and other conductors carrying low-frequency signals to pass through the barrier. If high-frequency signals must pass through the barrier a coaxial cable bulkhead connector can be added to the barrier, however, both the source of, and the load for, the high-frequency signals must be contained within a barrier, the cable and the load similar to the way the motor is contained within the barrier as shown in Figure 72.

It is essential that the process described in Figures 70 through 73 be strictly followed to eliminate noise problems from power-conversion devices. Any uncontrolled conductor that is allowed to penetrate the barrier, regardless of its importance, will carry noise current outside the barrier where it can be transferred to other nearby conducting material by inductive and/or capacitive coupling mechanisms or by direct conduction. There is no shortcut to the mitigation process.

Figure 74 shows an example of a successful installation of filters on the metal box containing the electronics for a variable-speed motor drive. In this case two filters were required since the system used both 120-V single-phase and 240-V three-phase electric power. The filters were bolted directly onto the side of the metal box, and care was given to ensuring that the filter case was in direct contact with the housing. An additional small box was added to each filter to provide physical support for the input power conductors. This filter prevented noise current and voltage from escaping the metal box on the power and green-wire ground conductors.

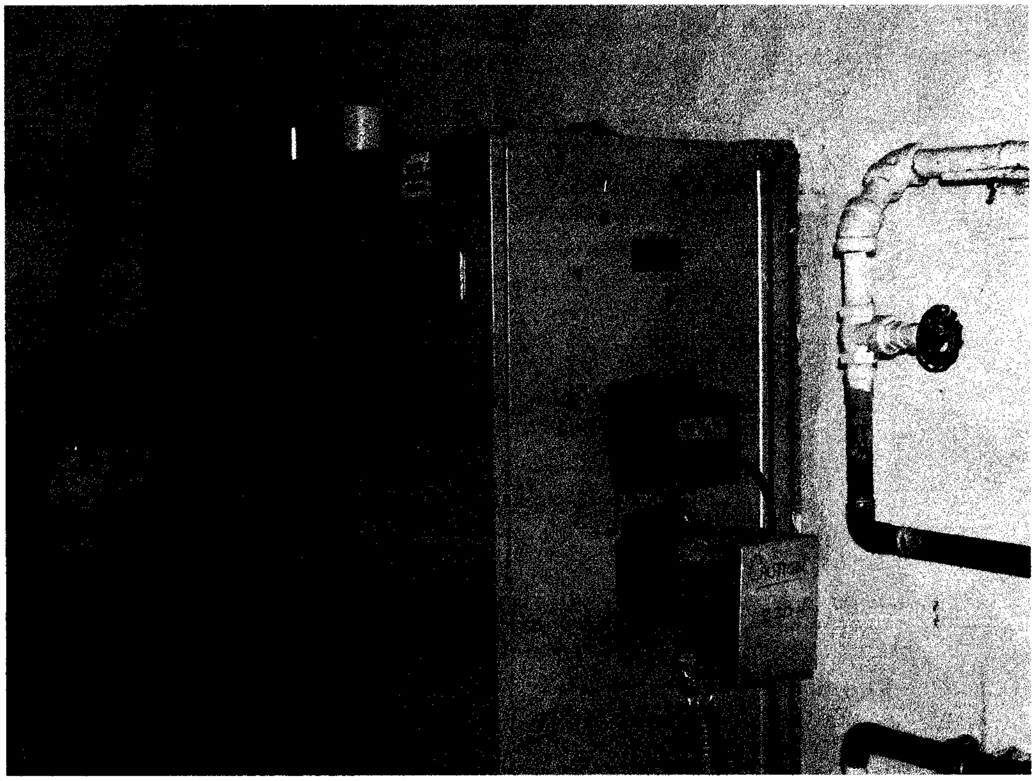

Figure 74 Filter Installation to Suppress Motor-Controller Noise

Conductors from the controller to two electric motors exited the case on its lower side. These conductors were inside conduits that ran from the controller's case to each motor, and the conduits were bonded to the controller's case and to the motor's housing. Additional conductors associated with an external control box used to adjust motor speed also exited the controller's case. These conductors were in a flexible shielded cable, and the shield was terminated at the controller's case and at the control-box case. No unshielded conductor that might carry noise current was allowed to penetrate the controller's case.

The modifications shown in Figure 74 proved to be highly effective in containing harmful levels of noise current within the controller's case, conduits and loads, and the procedure corrected a severe noise problem.

An example of an ineffective filter installation is provided to illustrate some common deficiencies that occur in improperly engineered attempts to solve electromagnetic-noise problems. Figure 75 shows a filter installed to prevent EMI current and voltage from causing problems at a receiving site. The filter was installed in a standard metal case that provided an excellent and acceptable shield around the filter.

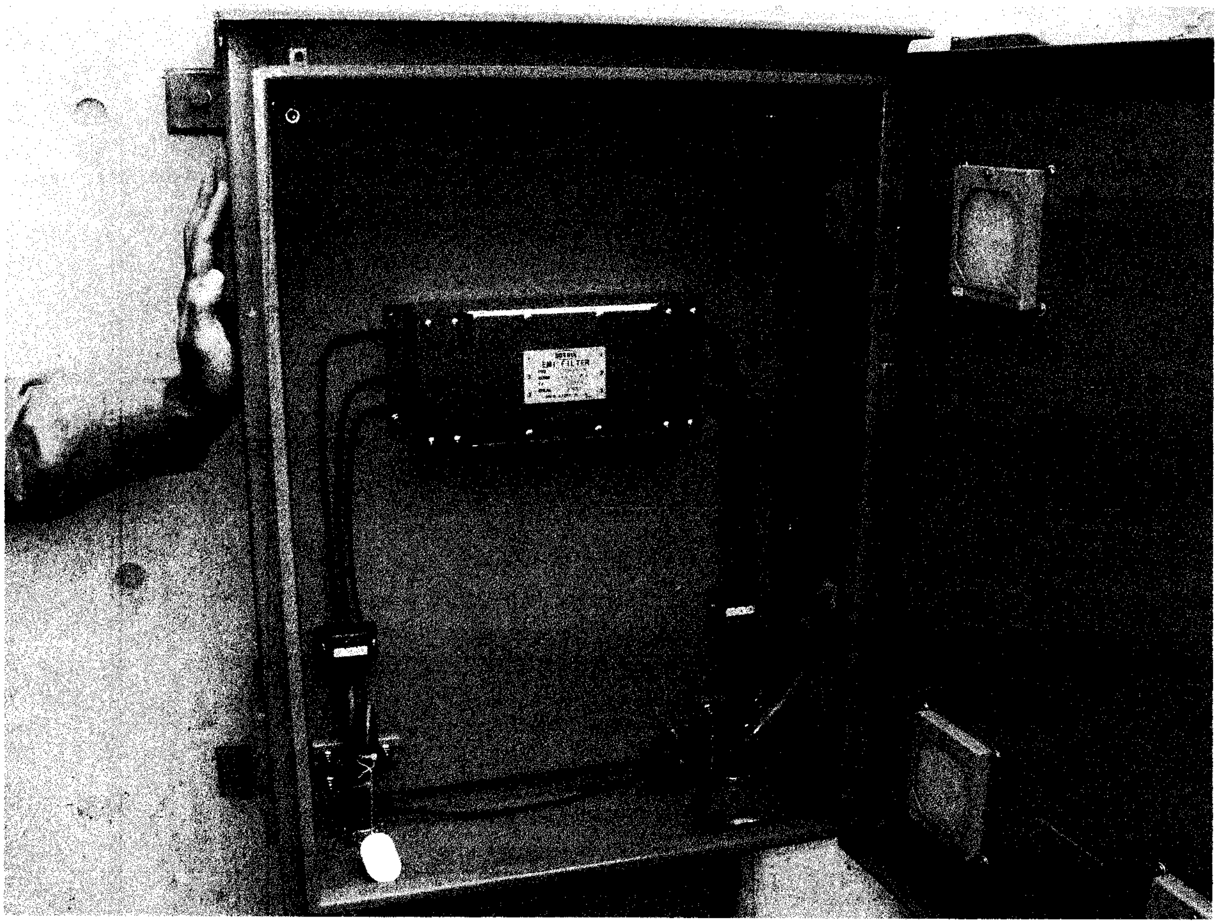

Figure 75 Improper Filter Configuration

Several improper aspects of the filter installation resulted in the total lack of suppression of a severe electromagnetic noise problem. These aspects are:

- Both input and output conductors penetrated a shield. The input conductors carried high levels of noise current. Some of this current was inductively and capacitively coupled to the interior surface of the shield case and in turn was inductively and capacitively coupled to the output conductors.
- The green-wire ground conductor also carried high levels of noise current and voltage. The input and output green wires were connected together, and this provided a direct conduction path for noise current and voltage to bypass the filter and be conducted to the output conductors.

- An examination of the source device showed that the conduit from the source to the filter housing was not terminated at the source device. This induced noise current and voltage onto the outside surface of the conduit. This noise current and voltage was then conducted to the filter box, onto the outside surface of the filter box, and onto the outside surface of the conduit running from the filter container to the motor. Since this conduit was bonded to other metal objects, noise current and voltage was conducted onto a number of other conducting objects. These conducting objects constituted a complex, but effective, radiator of the noise.

There is no simple corrective action that can be taken to alter or correct the deficiencies of the filter installation shown in Figure 75. In this case the source device was very small and its enclosure could be a small and inexpensive metal box along with the appropriate filters on its surface. The mitigation actions require:

1. The small source device itself must be enclosed in a small metal box.
2. All conductors entering and exiting this box must pass through filters with the exception of the green-wire ground.
3. The green-wire ground must be connected as shown in Figure 73.
4. Then remove the existing filter installation and reconnect all conductors in a normal configuration.

7. SUMMARY COMMENTS

This handbook is based on experience accumulated by the US Navy's Signal-To-Noise Enhancement Program (SNEP) teams over almost three decades of investigating Man-Made Radio-Noise problems at HF, VHF, and UHF receiving sites. Much has been learned from the detailed efforts needed to understand, document, and correct radio-noise problems. Many myths about radio noise were exposed and considerable progress was made in understanding sources, the impact of noise on signal reception, and effective noise mitigation procedures and well as ineffective procedures. During this time the team found that few electric utilities still maintain radio-noise specialists to aid in troubleshooting noise problems. In past years these individuals obtained decades of experience working on overhead and underground power lines problems and accrued much practical experience on solving radio-noise problems through trial and error. The SNEP teams learned to respect the detailed knowledge of these individuals about noise sources and noise mitigation. Unfortunately, the electric utilities are rapidly eliminating such positions for cost reasons, and trained replacements are simply no longer available.

Instrumentation to understand noise problems in a receiving site remains a major technical and management problem. New models of spectrum analyzers are simply not suitable to replace the old instruments used to investigate noise problems in sites. Current models cannot cope with the time-varying signal and noise problems encountered in receiving sites.

Nor are site planners, site managers and site staff trained to cope with the highly intermittent and erratic signal and noise conditions encountered. Of special concern is that the simple things like noise amplitude could not be described in normal terms of average, root-mean-square, or peak amplitude. Also, the more advanced terms of amplitude probability distributions, percent-of-time above a certain level, and other stationary statistical descriptors do not apply to the erratic noise conditions found at receiving sites. The noise encountered can only be described by complex non-stationary statistical procedures, suggesting that a valid description of noise is a highly complex mathematical process. This complex matter was avoided in this document by providing time-history examples of the noise. These examples illustrate the time and frequency changing properties of noise as well as its temporal variations with time.

To further complicate the matter, noise was mostly impulsive where the bandwidth of the noise was always wider than the receiver bandwidth. This results in the amplitude of impulsive noise being a function of receiver bandwidth. To partly cope with this major problem, the measurement bandwidth associated with each example of data is provided.

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Appendix A

NOISE-FREE DISTRIBUTION LINES

NOISE-FREE OVERHEAD DISTRIBUTION LINES

A.1 INTRODUCTION

The perverse nature and erratic occurrence of power-line noise complicate efforts to understand and eliminate its impact on receiving sites. To further confuse matters, some sections of distribution lines are completely free of sources of radio noise while other sections contain numerous sources. The differences are often poorly understood by electric-utility or public works personnel.

During the mitigation of power-line noise at receiving sites, sections of a number of distribution lines have been changed from noise-producing to noise-free lines. Distribution lines modified in accordance with the procedures described in this appendix have remained noise free for more than ten years. No section of a distribution line modified in accordance with these procedures has yet reverted into a noise-producing line. This success has shown that overhead distribution lines can be made noise free even though some are very close to receiving sites and some provide power to them. These cases have shown that overhead power lines can be built in the near vicinity of radio receiving sites which have no adverse impact on their reception of weak radio signals in the HF, VHF, and UHF bands. It is a matter of using line-hardware and line-construction techniques which inhibit the operation of noise sources.

While noise-free distribution lines can be built, there can be several roadblocks to achieving this goal. First, there is a considerable amount of misinformation available about the mechanisms of noise sources. Some of the misunderstood aspects of power-line noise have even achieved legendary and mythical status. Second, radio noise is often not a key consideration in the formulation of line-construction and line-maintenance practices and techniques by the electric utilities or public works departments. Each has its own set of guidelines for the construction and maintenance of overhead lines. These guidelines have evolved over many years into effective procedures for the efficient and low-cost delivery of electric power to customers. Sources of radio-noise on overhead distribution lines are an additional and separate aspect of this process often ignored because of the lack of information about sources or simple economics. Since radio-noise sources rarely affect the efficient and low-cost delivery of electric power, they are easily neglected or given secondary status by utility or public works personnel.

A.2 NOISE-FREE CONSTRUCTION AND MAINTENANCE TECHNIQUES

A.2.1 Background Information

This portion of Appendix A describes construction and maintenance techniques and practices which produce noise-free overhead distribution lines. The techniques and practices are specifically intended for use on distribution lines in the vicinity of HF, VHF, and UHF receiving sites. While some public works departments and some electric utilities now partly, or completely, follow these practices and techniques, others do not. Partial compliance with the techniques and practices will not provide noise-free overhead lines as turning out the lights in a room seldom makes the room completely dark.

SPECIAL NOTE

In the past it was recommended that overhead power lines not be allowed within two or three miles of a receiving site. This recommendation has not been strictly followed, and many violations of this recommendation exist near receiving sites. The list of violations includes many overhead power feeds to receiving sites. Unfortunately, the concept of the two and three mile distance limits is not supported by technical data or by technical analyses. These limits are ineffective, and they must be disregarded.

In actual practice, all overhead distribution lines within line of sight of the uppermost part of the antennas at a receiving site must be free of harmful noise sources. A practical maximum distance limit is not feasible until a distance of about 30 km from a receiving site is reached.

A.2.2 New Overhead Line Construction

Whenever possible, encourage the use of underground power lines with customer service transformers installed in metal enclosures on concrete pads for all new construction within line of sight of an HF, VHF, or UHF receiving site. When this is not feasible due to cost, lack of right of way, or other problems, new overhead lines and new extensions to existing lines can be made noise free by strictly complying with the following line-construction practices. These practices are directed at the prevention of sources of radio noise on new distribution lines, new extensions to existing lines, and new customer-service connections. The practices and techniques apply to all single-phase and multiple-phase distribution lines operating at line-to-line and line-to-ground voltages from 2 kV up to 35 kV.

Lower voltage secondary lines seldom contain source of noise although they sometimes carry customer-generated noise onto overhead power lines. Customer-generated noise will pass through distribution-line transformers with little or no significant attenuation; the suggestion that such transformers will isolate noise sources from overhead distribution lines is inaccurate.

A.3 NOISE-FREE TECHNIQUES FOR NEW LINE CONSTRUCTION

A.3.1 Insulators:

- Do not use ceramic or glass bell insulators on new lines. Use only polymer type insulators for suspension or tension insulators. Use a polymer insulator with a voltage rating one level above the line-to-line and the line-to-ground voltage. This ensures that sufficient line-to-pole spacing is provided to prevent the activation of noise sources associated with the insulator attachment hardware.
- Do not use spool insulators on new distribution lines. Replace spool insulators with polymer-type insulators which have a voltage rating one level above the line-to-line and the line-to-ground voltage. This ensures that sufficient line-to-pole spacing is provided to prevent the occurrence of noise sources associated with the insulator support hardware.
- Do not use pin insulators and pin bolts. Use post insulators to avoid loose internal screw joints.
- Use post insulators with bare conductors and bare preformed tie wires whenever possible.
- When post insulators with saddle clamps are used, ensure that the saddle clamp is tightened sufficiently to eliminate any possibility of line-conductor movement in the saddle clamp.
- Do not install elastomer pads on the top of pin or post insulators to provide a soft cushion for the conductor. If unusual wear is anticipated, use a preformed line-reinforcement sleeve.

A.3.2 Tie Wires

- Use bare preformed tie wires on bare conductors whenever possible.
- Do not use insulated tie wires on either insulated or bare conductors unless the tie-wire conductor is firmly bonded to the line conductor.
- If insulated line conductors are used, firmly bond each tie-wire conductor to the line conductor.
- If bare tie wires are used on bare conductors, use preformed tie wires or ensure that wrapped tie wires are firmly bonded to the line conductor.
- Do not use plastic, semi-conductor or other non-conducting tie wires.

A.3.3 Hardware

- Do not use lag screws on wooden poles or crossarms. Use through-bolts, and install a combination of a large flat washer and two-turn lock washers or spring washers on all bolts to spread the pressure over a larger surface and reduce the incidence of loosening from wood shrinkage.
- Ensure that a minimum of 1½ inch spacing is maintained between all unbonded metal objects. This includes the spacing between ground and guy wires and all other conductive objects.
- Bond all unenergized objects to earth ground. Leave nothing floating. If metal towers are used to support a distribution line, bond all unenergized objects to the metal tower and ground the tower. Insure that all tower joints are tight.
- On wooden poles, use only insulated staples to support ground wires. Do not use bare staples.
- Use only pressure treated components for wooden construction. Never use untreated wooden poles, crossarms, or other components which are subject to shrinkage and premature failure.

A.4 NOISE-FREE TECHNIQUES AND PRACTICES FOR EXISTING LINES

Noise sources on existing distribution lines can be eliminated as long as the line-support hardware already meets good, normal construction standards. Do not try to eliminate sources on lines containing dry-rotted wooden components or other abnormal construction until the public works department or electric utility operating the line corrects such deficiencies and brings the lines up to good condition.

The following procedures and practices will eliminate sources of noise on distribution lines operating at line-to-line or line-to-ground voltages from 2 kV up to 35 kV.

A4.1 Insulators

- Where a bell insulator is identified as a noise source, replace all bells on the same pole with polymer-type insulators. Use polymer insulators with a voltage rating one step higher than the line-to-line or line-to-ground voltage.
- Never replace a bell insulator with another bell insulator.
- Replace pin insulators found to be noisy with post insulators.
- Eliminate all spool insulators, except those on secondary lines (600 V or less).

A4.2 Lightning Arresters

- Immediately remove every lightning arrester identified as a source of noise. Replace each with a new arrester of the appropriate rating.
- Remove all lightning arresters with discoloration on the bottom ceramic ring of the arrester or if the bottom ground conductor has separated from the arrester. Replace them with new arresters of the appropriate rating.
- Check all lightning arresters within line of sight after each major lightning storm. Immediately remove and replace all damaged or noisy arresters.

A4.3 Hardware

- Tighten all hardware on each pole identified with a source of noise.
- Remove all lag bolts on wooden poles containing a source of noise and replace them with through bolts. Add large flat washers and two-turn lock washers or spring washers to each bolt.
- Replace all wooden components, such as crossarms and poles, suffering dry-rot damage since hardware cannot be tightened sufficiently to keep poles free of sparking sources. Use only pressure-treated wooden components.
- Maintain 1½ inch or greater spacing between unbonded metal objects.
- Bond all metal objects together. On wooden pole construction run a ground wire to an earth ground. On steel towers, use the tower as a ground conductor.
- Use insulated staples to support ground wires on wooden poles. Replace damaged staples. Never use uninsulated staples.

A.5 INEFFECTIVE ACTIONS

Field experience has shown that many corrective or repair actions taken do not lead to noise-free overhead distribution power lines. Knowledge of these items avoids wasting time, resources, and money on useless mitigation actions. Most of the ineffective actions are based on popular myths about power lines and their noise sources. Some of these things are listed below.

- Do not wash insulators on a distribution line. It is not an effective noise-mitigation technique, and the process may be very misleading. Dirty insulators on a distribution line rarely are a source of radio noise. The moisture from washing an insulator will temporarily render most sources inactive. They will become active again as soon as the source mechanisms dry. Dirty insulators can sometimes cause a power delivery problem in heavy industrial areas and in high-humidity areas which support the growth of fungus on insulators. Utility personnel in the affected areas are well aware of this problem, and they can take the necessary corrective actions to keep power flowing.

- Do not waste time on noise sources which do not affect the performance of a receiving site. If a source does not affect the ability of a receiving site to receive radio signals, ignore it. Attention to such sources is a needless waste of time and resources. Concentrate on those sources that do affect the performance of a receiving site.

- Do not expect public works or utility personnel to find the sources that affect the operation of your site based only on general radio-interference complaints. This rarely works. Public works and utility personnel do not normally have access to your site; hence, they do not know what kind of noise is adversely affecting your site. Successful and effective mitigation actions start within a receiving site. The determination of the general activity of each source and the fine-scale temporal and spectral structure of each source of power-line noise which adversely affects radio-signal reception are key items needed to start the identification and location process. Also, your noise may not originate from a power line. Noise from many other electrical sources can be very similar to that from power lines. Be completely sure that your problem is related to power lines and document each case of radio interference before you involve public works or utility personnel.

- Never hammer or shake distribution-line poles or guy wires. This action induces movement along several spans of line, and it rarely provides the information needed to identify the pole containing a specific source affecting a receiving site. In addition, serious safety issues arise since even the slight movement of a pole can result in the failure of line-support hardware. Locate poles containing noise sources with the radio techniques described in the main body of this handbook.

- Untrained personnel must not touch guy wires, switch handles, fuse blocks, or other hardware on a pole. This is not necessary to locate sources, and such hardware should always be treated as energized, as it is often energized through leakage current and/or by induction. Leave all pole work up to public works or utility personnel who have had many years of training on safety issues and are qualified to work on overhead lines.

- Never rebuild a section of overhead lines in a blind attempt to use this gross approach to eliminate sources of radio interference. This is a costly and ineffective approach that often winds up with more sources that previously existed. This approach will work only when the noise-free techniques described in this appendix are employed. If a section of line has deteriorated to the extent that it is unusable or unsafe, then utility or public works personnel must correct such problems in accordance with noise-free techniques and practices.

A.6 ADDITIONAL COMMENTS

The authors have encountered a number of practical problems in implementing noise-free practices and procedures on distribution lines. Each public works department or utility constructs and maintains their lines in accordance with established practices and procedures. Line hardware is purchased and stocked to meet these practices and procedures. Linemen are trained to strictly follow established practices and procedures and to use only approved hardware. It is often useful to obtain a copy of the line-construction and line-maintenance procedures used by the public works department or the utility operating overhead distribution lines with noise sources.

Changing the procurement, stocking, and installation process to use noise-free components and procedures (e.g., the use of polymer insulators in place of the old reliable bell insulators) is often a complex process. Changing the line-construction techniques (e.g., the elimination of insulated tie wires) also can be a time-consuming process that often requires fundamental changes in old established procedures and changes in the training of lineman. Yet these obstacles can be overcome provided the technical aspects of the need for change are justified to the line operators.

Another major problem is that the managers and operators of receiving sites usually lack detailed knowledge about power lines, the terminology used by line operators, noise-source mechanisms, effective source-location techniques, and effective mitigation actions. Since radio interference from sources associated with overhead power-lines is the major factor adversely affecting the reception of signals at most HF/VHF/UHF receiving sites, serious attention to this plaguing problem is needed. This handbook was devised to aid in this problem.

Still another problem is that the physical aspects of power lines seldom remain static. Line updates, new higher-capacity lines, lines to serve new customers, and line-maintenance actions are continuously underway. This is especially the case in growing and developing areas. Thus, noise mitigation will be a moving target unless there is effective and ongoing coordination and cooperation between the site and the public works department or the electrical utility operating the lines. The use of noise-free techniques and practices during distribution-line modifications, line maintenance, and the installation of new lines will prevent ongoing noise problems.

There are no restrictions on the reproduction and distribution of this handbook. Provide copies of it to all utility and public works organizations operating distribution lines within line of sight of a receiving site, and encourage them to follow the noise-free practices described.

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Appendix B

SIGNALS LOST FROM SITE PARAMETERS AND MAN-MADE RADIO NOISE

B.1 THE PERFORMANCE EVALUATION TECHNIQUE (PET-2A)

A program named the Performance Evaluation Technique (PET) was developed by the staff and students of the Naval Postgraduate School to evaluate the ability of an HF site to receive radio signals. This program was improved during more than two decades of staff and student participation in radio-noise and signal-reception surveys at receiving sites, eventually developing into version PET-2A[4]. This is a relatively simple program using the HF propagation prediction program (PROPHET) and spreadsheets (Lotus 123). Any similar propagation prediction program or spreadsheet program can be used.

PET-2A is a flexible program that can accommodate a number of HF communications signal formats including conventional signal formats such as frequency-shift-keyed, spread-spectrum, single sideband, amplitude modulation, Morse Code, and other signal formats. It is also useful for use with short-duration signals as long as the input data is collected over the short times of interest.

The PET-2A program calculates the effects of the following items on the reception of signals from a distant source:

- source transmitter power,
- type of source transmitting antenna,
- type of the modulation,
- ionospheric radio-propagation conditions,
- type of receiving antenna,
- RF path loss from the receiving antenna to the receiver,
- radio noise introduced by components in a site's RF path,
- site's receiver bandwidth,
- site's receiver sensitivity, and
- man-made radio-noise levels at a site.

Signal sources are chosen within the primary and secondary coverage areas of a site. The primary coverage area of a receiving site is defined as that area within one ionospheric hop of the site location. The secondary coverage area is defined as the area between the one-hop limit and the two-hop limit. A source in the secondary coverage area will typically provide signal levels 10- to 20-dB lower than the same source when located in the one-hop area. The reception of signals from sources beyond the two-hop limit is considered to be too unreliable for consistent reception.

As part of the analysis, a great-circle map is typically generated to show the one-hop and the two-hop coverage areas for each site examined. This map provides an overview of the areas of the globe that can be effectively covered by a radio-receiving site.

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[4] Wilbur R. Vincent and Richard W. Adler, *A Method of Evaluating the Ability of Naval Receiving Sites to Detect and Process Data from Signals of Interest*, Technical Memorandum PET9608, Signal Enhancement Laboratory, Electrical and Computer Engineering Department, Naval Postgraduate School, Monterey, CA, August 1996